

NASA Contractor Report 2901

NASA
CR
2901
v.2
c.1

LOAN COPY: RETURN
AFWL TECHNICAL FILE
KIRTLAND AFB, N.M.



Computation of Unsteady Transonic Flows Through Rotating and Stationary Cascades

II - User's Guide to
Fortran Program B2DATL

Edgar Alzner and Paul P. Kalben

CONTRACT NAS3-16807
NOVEMBER 1977

NASA



NASA Contractor Report 2901

Computation of Unsteady Transonic Flows Through Rotating and Stationary Cascades

II - User's Guide to Fortran Program B2DATL

Edgar Alzner and Paul P. Kalben
Advanced Technology Laboratories, Inc.
Westbury, New York

Prepared for
Lewis Research Center
under Contract NAS3-16807



National Aeronautics
and Space Administration

**Scientific and Technical
Information Office**

1977

TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION	1
OVERVIEW	1
DESCRIPTION OF THE COMPUTATIONAL DOMAINS	1
OUTLINE OF METHOD OF SOLUTION	6
LIMITATIONS AND RESTRICTIONS	10
OPTIONS	13
PROGRAM INPUT	14
UNITS	14
INITIAL PROGRAM SUBMITTAL	15
RESTARTING THE PROGRAM	28
SAMPLE INPUT	29
PROGRAM OUTPUT	29
INPUT DATA	30
INITIAL DATA AND CONSTANTS	30
INTERMEDIATE OUTPUT	31
DOMAIN OUTPUT	32
PROGRAM STRUCTURE	34
FLOW CHART OF OVERALL PROGRAM	34
INDIVIDUAL ROUTINE FLOW CHARTS	34
DESCRIPTION OF SUBROUTINES	34
DICTIONARY OF PRINCIPAL VARIABLES	45
MACHINE CONTROL CONSIDERATIONS	52
ABNORMAL TERMINATIONS	53
APPENDIX A - SAMPLE OUTPUT FROM PROGRAM B2DATL	57
APPENDIX B - SUBROUTINES AND COMMON BLOCKS WHICH MUST BE CHANGED TO INCREASE THE MAX- IMUM VALUES OF JS+1 and KS+3	73
APPENDIX C - PROGRAM LISTING AND AVAILABILITY	75
REFERENCES	76

LIST OF FIGURES

	<u>Page</u>
FIG. 1 SCHEMATIC OF BLADE ROW INTERSECTION WITH A STREAM SURFACE, AND COORDINATE SYSTEMS	2
FIG. 2 DETAIL OF STREAM SURFACE COORDINATE SYSTEM WITH FINITE THICKNESS STREAM SHEET	3
FIG. 3 BLADE-TO-BLADE COORDINATE SYSTEM AND GRID NETWORK	4
FIG. 4 SCHEMATIC REPRESENTATION OF PHYSICAL AND COMPUTATIONAL DOMAINS	7
FIG. 5 GRID ROW ORDERING IN VICINITY OF BLADES AND SLIPSTREAMS	8
FIG. 6 INPUT FORM	16
FIG. 6 INPUT FORM (Continued)	17
FIG. 6. INPUT FORM (Continued)	18
FIG. 7 CALLING RELATIONSHIP OF SUBROUTINES IN PROGRAM B2DATL	35
FIG. 8 FLOW CHART OF MAIN ROUTINE B2DATL	36
FIG. 8 FLOW CHART OF MAIN ROUTINE B2DATL(Continued)	37
FIG. 9. FLOW CHART OF SUBROUTINE UNCOM2	38
FIG. 9 FLOW CHART OF SUBROUTINE UNCOM2(Continued)	39
FIG. 9 FLOW CHART OF SUBROUTINE UNCOM2(Continued)	40
FIG. 9 FLOW CHART OF SUBROUTINE UNCOM2(Continued)	41

INTRODUCTION

Overview

The FORTRAN IV program B2DATL calculates the two-dimensional unsteady flow through axial turbomachinery on a blade-to-blade stream surface, as illustrated in Figure (1). Variations of the stream surface radius and thickness in the direction orthogonal to the stream surface, as shown in Figure (2), are incorporated into the formulation, thus providing a quasi three-dimensional analysis. The computational domain consists of one blade-to-blade passage which is divided into seven (7) sub-domains. The analysis and computational methods are described in detail in Reference (1). The flow field solution is computed at interior grid points by a shock capturing, finite difference, time-marching technique using the MacCormack algorithm. The boundary points are evaluated either by enforcing an appropriate boundary condition through use of the reference-plane method of characteristics, (with translating coordinate systems to minimize the cross flow effects) or by interpolation of data from the flow field in adjacent sub-domains and in adjacent blade-to-blade passages (with an appropriate phase lag in time).

Description of the Computational Domains

As shown in Figure (3), the region in which the computation is carried out consists of up to seven (7) domains, which contain the two blade rows and segments of the stream surface extending upstream and downstream of the rows and between the rows. The domains are limited in the circumferential direction by the blade-to-blade spacing of the two respective blade rows. The blade slipstreams form the lateral boundaries of domains 4, 6 and 7. The lateral boundaries of domains 1 and 2 are aligned along a direction defined by the mean angle of the leading edge of the blades in domain 3. Not all seven domains need be used in all cases. Both blade rows can be either rotating or stationary and a single blade row can also be analyzed.

The meridional chord lengths, CE1 and CE2, of sub-domains 3 and 5, respectively, are determined by the projection of the blade chord on the meridional coordinate (the intersection of the meridional plane and the stream sheet surface). The meridional lengths of domains 2 and 6 are also set equal to CE1 and CE2, re-

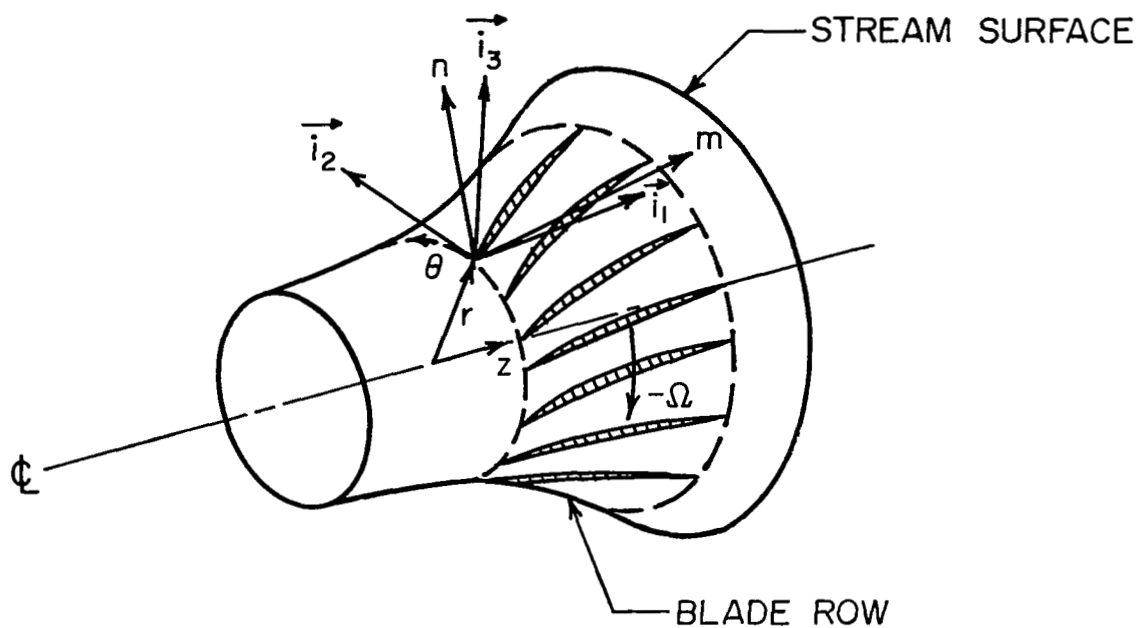


FIGURE 1. SCHEMATIC OF BLADE ROW INTERSECTION WITH A STREAM SURFACE, AND COORDINATE SYSTEMS

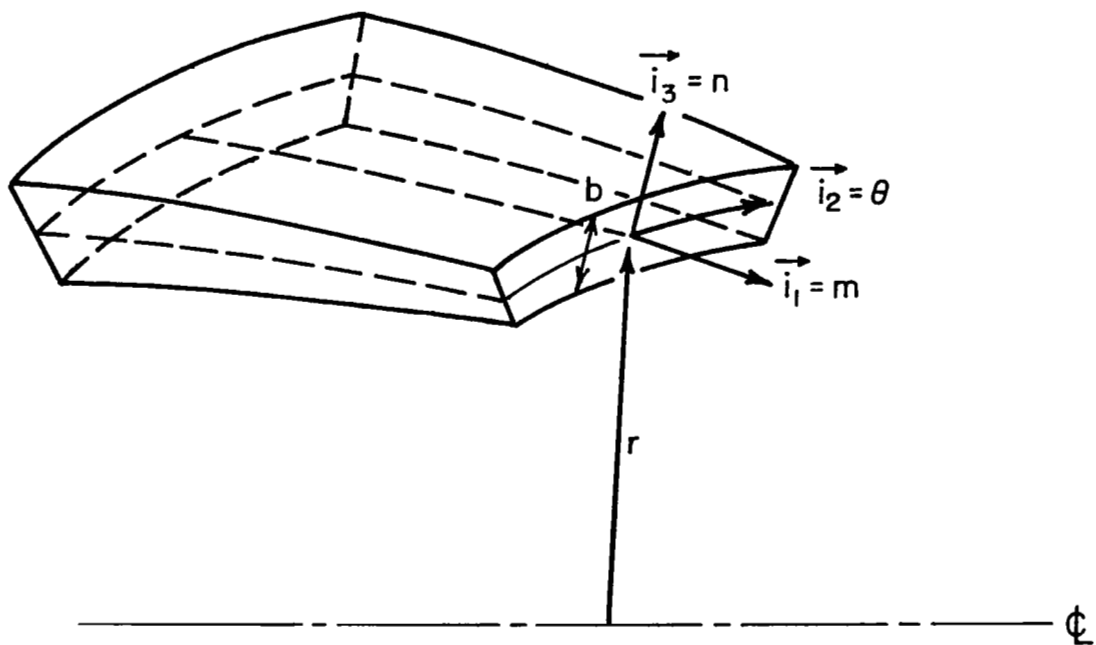


FIGURE 2. DETAIL OF STREAM SURFACE COORDINATE SYSTEM
WITH FINITE THICKNESS STREAM SHEET

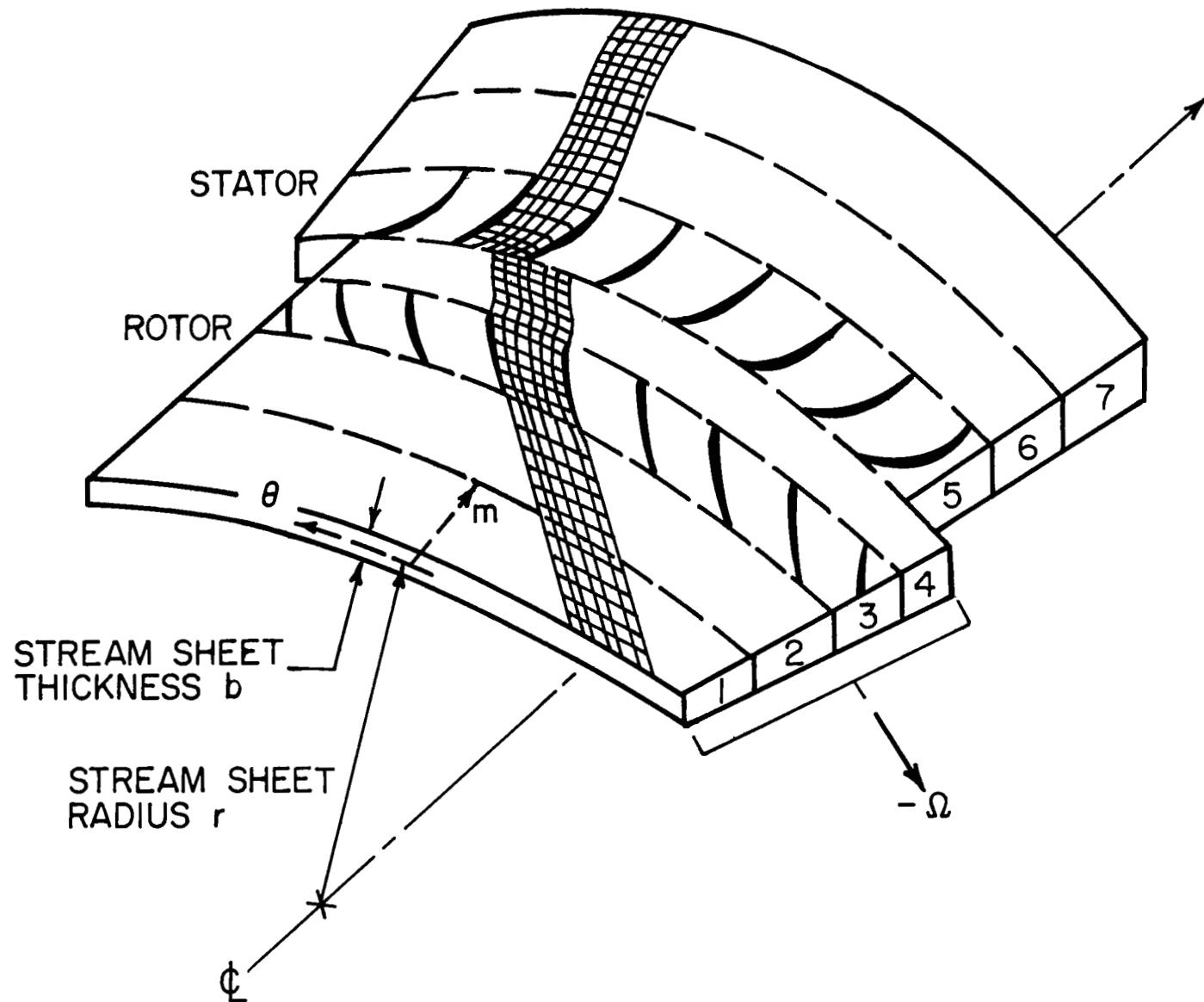


FIGURE 3. BLADE-TO-BLADE COORDINATE SYSTEM AND GRID NETWORK

spectively. The length C_4 is equal to the meridional distance between the two blade rows. The meridional lengths of domains 1 and 7, CE_0 and CE_7 , are the distances from the selected inflow and outflow boundaries (discussed later) to the entrance of domain 2 and to the exit of domain 6, respectively. If the inflow and outflow boundaries are precisely one chord length upstream of the first blade row and downstream of the second, respectively, then sub-domains 1 and 7 are deleted.

The frame of reference of domains 1 through 4 is attached to the first blade row, and the blade spacing in this row determines the circumferential extent of these domains. The frame of reference of domains 5 through 7 is attached to the second row with a corresponding determination of the circumferential extent of these domains. The rotational speed of each blade row is independently specified (i.e., either or both can be rotating, subject to a restriction on their relative motion which will be stated later). If only one blade row is analyzed, domains 4 and 5 are deleted and domain 6 interfaces with domain 3 in the same manner as it interfaces with domain 5 when two blade rows are considered. Domains 1 and 7 may also be deleted in this case.

The axial stations defined by a common meridional coordinate of two adjacent domains are defined as "vertical" boundaries. In addition, the inflow and the outflow boundaries are termed "vertical" boundaries. The inflow boundary is situated at the beginning of domain 1 (or at the beginning of domain 2 if domain 1 is deleted), while the outflow boundary is situated at the end of domain 7 (or at the end of domain 6 if domain 7 is deleted).

The blade surfaces, the slipstreams, and the upstream extensions of the leading edges of the first blade row through domains 1 and 2 are termed "horizontal" boundaries. The slipstreams alter their shape in time due to their motion in an unsteady flow field. In addition, for cases in which viscous effects are considered, the "effective" surfaces of the blades also change their shape in time as a result of a time varying displacement thickness of the boundary layer.

A transformation of coordinates which "stretches" the physical (m, θ) plane into the transformed (σ, v) plane is detailed in Reference (1) and shown in Figure

(4). Each of the seven transformed domains thus have coordinates σ and v which range from 0.0 to 1.0. The subscript J is used in the σ direction, with a maximum value $JSP = JS+1$ (where JS is an input parameter). The subscript K is used in the v direction, with a maximum value of $KS+3$ (where KS is an input parameter). Ordering of the grid columns and rows is shown in Figure (5). $J=2$ corresponds to $\sigma = 0.0$ and $J=JS$ corresponds to $\sigma = 1.0$. The values of $K=3$ and $K=4$ at $v = 0.0$ as well as the values of $K=KS$ and $K=KS+1$ at $v = 1.0$ carry the same v coordinate value. This dual notation is necessary since leading and trailing edges as well as slipstreams must accommodate double-valued solutions at the same physical location. Each domain is defined by the limits $J=2$ on the left and $J=JS$ on the right in the meridional direction, and by $K=4$ at the lower boundary and $K=KS$ at the upper boundary in the circumferential direction. Values of J and K outside of these ranges denote "virtual" points. These are needed to define flow properties outside the boundaries of the domain such that derivatives and/or interpolated values can be obtained at the respective boundaries, as needed. For example, the compatibility relationships at a slipstream point must be evaluated from flow properties pertaining to each side of the slipstream. The interior ($4 \leq K \leq KS$) of a domain bounded by a slipstream provides data for one relationship and the exterior ($3 \geq K \geq KS+1$) provides data for the other.

Outline of Method of Solution

The computational process is divided into a number of subroutines. The computation begins in the main program B2DATL for either an initial run or restart of a previous run. Input data is read, the flow field is initialized, and mesh size, as well as the time step (in an initial run only), are evaluated. The initial data for each time step is stored in arrays $P1(ID,J,K)$, $R1(ID,J,K)$, $U1(ID,J,K)$, $V1(ID,J,K)$ and $E1(ID,J,K)$ which represent the static pressure, static density, meridional velocity, relative circumferential velocity and relative total internal energy, at the mesh point identified by (ID,J,K) . ID varies from 1 to 7 and identifies the domain, J varies from 1 to $JS+1$ and identifies the meridional grid column and K varies from 1 to $KS+3$ and identifies the circumferential grid row. Subroutine UNCOM2 is called by B2DATL to perform the execution, output and termination of a run. No return is made to B2DATL.

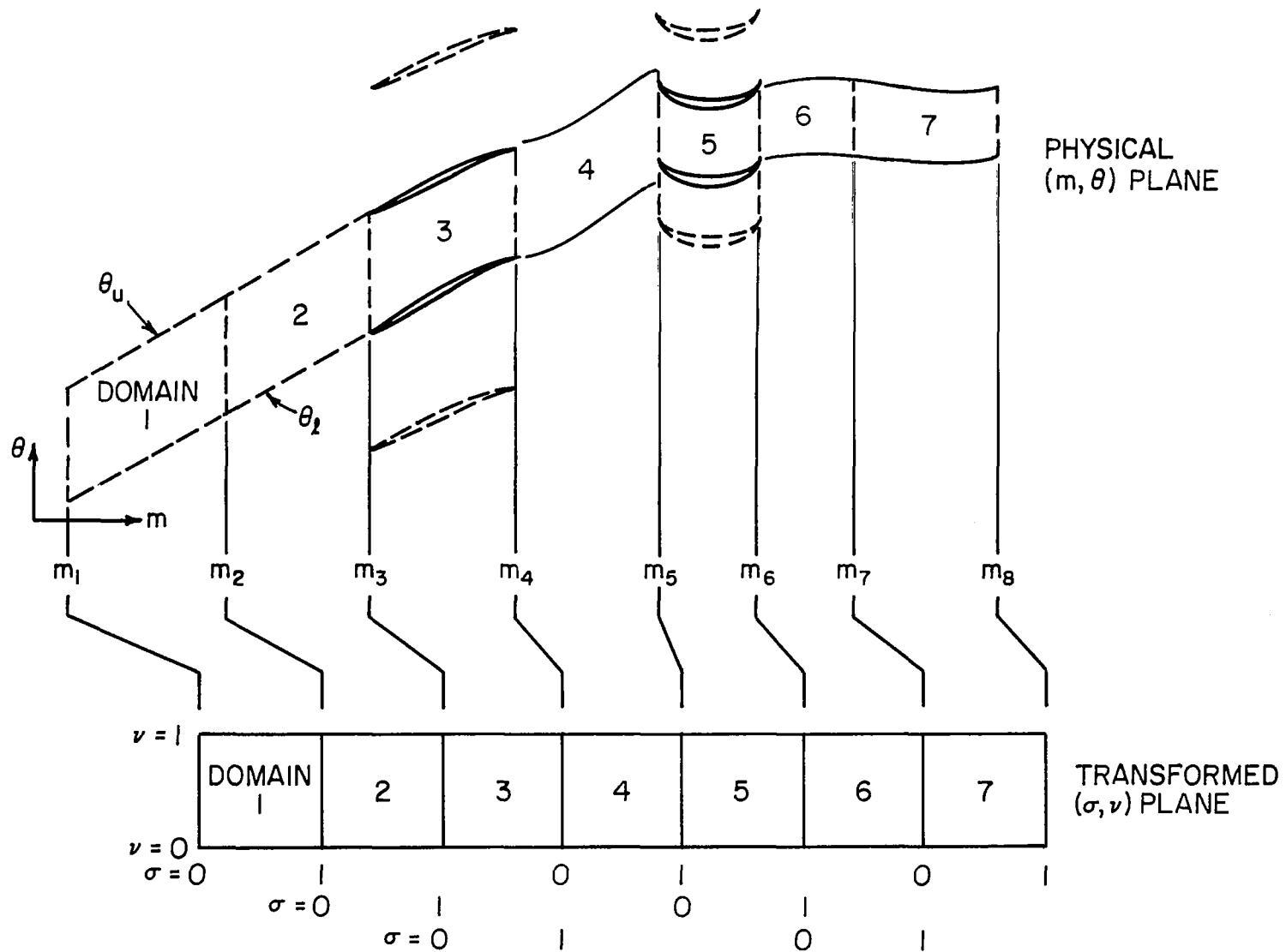


FIGURE 4. SCHEMATIC REPRESENTATION OF PHYSICAL AND COMPUTATIONAL DOMAINS

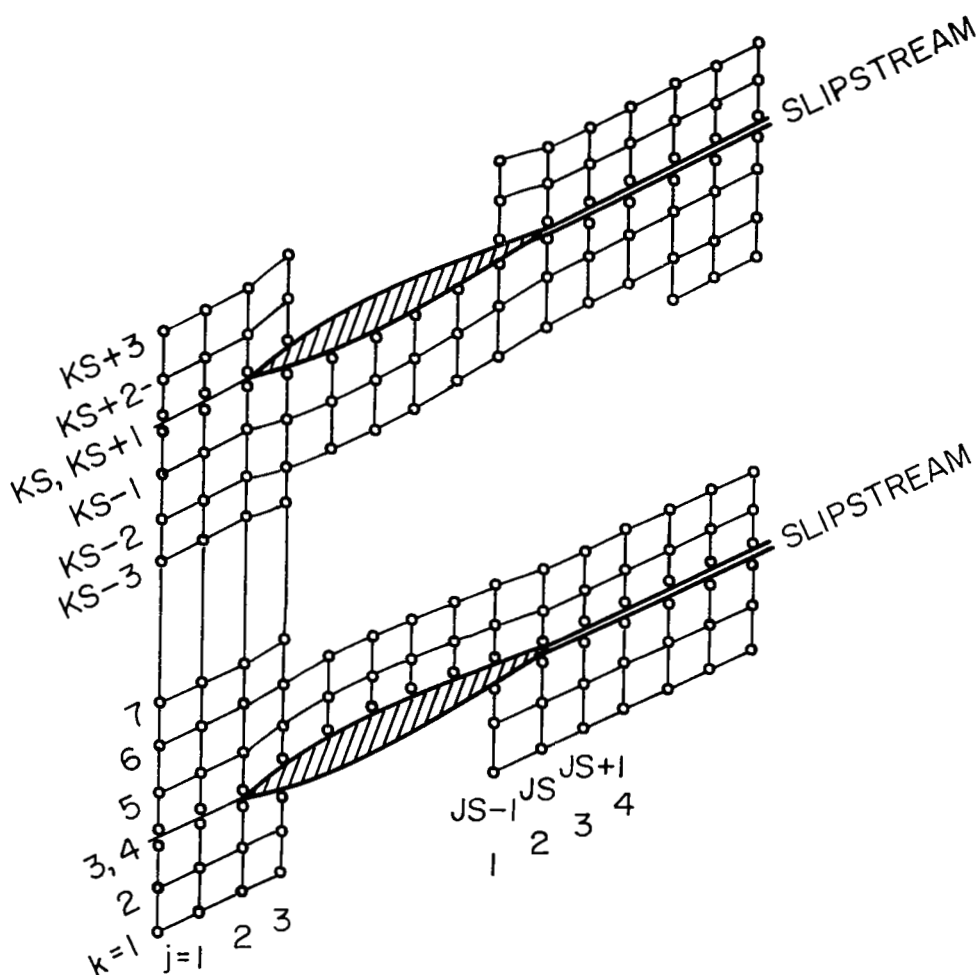


FIGURE 5. GRID ROW ORDERING IN VICINITY OF BLADES AND SLIPSTREAMS

(Note that one of the three dependent variables, P, R and E, is redundant, since the equation of state can be used to determine the internal energy from the pressure and density. Therefore, only two of these three variables must necessarily be stored, since the third could be evaluated locally as needed. This would result in a reduction of the storage requirements, but evaluation of the redundant variable each time it is needed would increase the computation time. Therefore, a tradeoff between computation time and storage must be made.)

Subroutine UNCOM2 takes the computational process through the predictor and then the corrector evaluation of the interior points of the flow field and the evaluation of all boundary conditions. Both the predictor and corrector values are stored in the arrays P2(ID,J,K), R2(ID,J,K), U2(ID,J,K), V2(ID,J,K) and E2(ID,J,K), i.e., the predictor values are overwritten by the corrector values as they are computed. The computational grid is swept out by columns, beginning with J=1, in each domain. Hence, care has been taken to use temporarily stored predictor values at the grid point (ID,J-1,K) and (ID,J,K-1) when evaluating spatial derivatives of predictor variables at (ID,J,K), for the corrector step. The interior point algorithm is executed by ITER1, which is called twice per time step from UNCOM2 (see Reference 1 for details of the MacCormack scheme). UNCOM2 continues with the boundary point calculations, some of which need only be done once per time step, as will be described later. After ITER1 is called the first time, with the integer flag ITER = 1, all boundary condition subroutines are called. These subroutines are of two types:

- a) Those called only once (after the first call to ITER1), namely TRED, SURF, SLIP and ONESID. These subroutines use algorithms based on reference plane characteristics.
- b) Those called after each call to ITER1, namely VEB1, VEB4, VEB5 and HØBA. These subroutines equate boundary point flow properties to those in adjacent domains at both vertical and horizontal boundaries.

UNCOM2 continues this sequence, including calls to output routines as requested, until a specified number of time steps has been completed.

Limitations and Restrictions

There are certain operating limitations and restrictions inherent in Program B2DATL. The most fundamental limitation pertains to the minimum grid point density which will yield a meaningful solution. This limitation depends on the particular geometry and flow conditions of the case being run. Some test cases have been run with as few as five mesh points in each direction, (JS=6 and KS=8). However, in one case 17 points in the meridional direction (JS=18) and 9 points in the circumferential direction (KS=12) were the minimal number which yielded a successful run. There is no generalized rule that can be applied to cover all contingencies other than to indicate that the larger the curvature of a blade surface or the more complex the geometry of the configuration, the more mesh points are needed. The present maximum grid density is 17 by 9, i.e., JS=18 and KS=12. Higher densities would be desirable in most cases, but storage limitations in the computer system used during development of the code precluded this.

The following general restrictions must also be observed:

- 1) The lengths of domains 1, 4 and 7 (CE0, C4 and CE7, respectively) relative to domains 3 and 5 must satisfy the following conditions:

$$CE0 \geq CE1/(JS-3)$$

$$C4 \geq CE1/(JS-3)$$

$$C4 \geq CE2/(JS-3)$$

$$C7 \geq CE2/(JS-3).$$

- 2) Although either blade row can rotate or be stationary, the motion of one blade row relative to the other is restricted by the relationship:

$$\emptyset MG(2) - \emptyset MG(1) \geq 0$$

where 1 refers to the first or upstream blade row and 2 to the second or downstream row.* (This restriction results from an assumption as to the direction of relative motion between domains 4 and 5 made in the

*Note that this restriction can be circumvented by reversing the true direction of rotation and running the mirror image of the actual blade contours.

coding, rather than any restriction in the analysis.)

- 3) The number of blades in the second row must be greater than or equal to the number of blades in the first row. In addition, the ratio of the number of blades is limited to 3 to 2, i.e.:

$$1 \leq \frac{M\text{ØBL}}{N\text{ØBL}} \leq \frac{3}{2}$$

where $N\text{ØBL}$ is the number of blades in the first blade row and $M\text{ØBL}$ is the number in the second blade row.

- 4) The evaluation of vertical boundary points at the interface between domains 4 and 5 (when two blade rows are run) is carried out in VEB4 and VEB5 by interpolation of data which is provided over a limited circumferential range. The circumferential range encompasses three adjacent blade-to-blade passages, and the arrays containing this data are composed of flow variables with a time-phase lag appropriate to that particular instant and location, for both the inflow boundary of domain 5 and the interpolation plane in domain 4. At any one instant of time the motion of the slipstream bounding domain 4 must be such that interpolated points fall inside of the range of available data. If the slipstream motion extends the slipstream position beyond the available range of data, interpolation will not be possible and the program will terminate with an error message. If this termination condition is encountered, the only control which the user can exercise over the slipstream motion is an artificial damping of the slipstream velocity, which is discussed below.

Restrictions number (3) and (4) above both result from the limited range of data which is stored along the interface between domains 4 and 5. Both could be removed if instead of three blade passages of vertical boundary data, five blade passages of data were stored. This would involve a major modification to the program but is nevertheless feasible, and would permit a ratio of up to 5/2 in the number of blades instead of 3/2.

A very important feature of the solution process is the capability to restrict the movement of the slipstream. This capability is exercised through the parameters DAMPC, DAMPC1, DAMPI and DAMPI1 which are defined in Section IIA "Initial Program Submittal". When a case is started, the initial data is at best an approximation to the conditions that should exist at that instant. After a number of time steps (typically between 100 and 300) most of the major disturbances associated with the initial data will have propagated out of the computational domain, and reasonably modest oscillations about the asymptotic solution can be expected. Until the flow field has "settled down" from the initial transient, it is beneficial to restrict the slipstream motion in order to avoid violent slipstream oscillations. Once the flow field has "settled down" sufficiently, the slipstream motion can be gradually allowed to assume its full, unrestricted behavior. The slipstream motion is restricted by multiplying the slipstream velocity by a specified function. This function is a constant, DAMPC, for time steps less than a specified number, DAMPI. For time steps greater than another specified number, DAMPI1, the function is a second constant, DAMPC1. In the intermediate range of time steps from DAMPI to DAMPI1, the function has a cosine variation from DAMPC to DAMPC1. The extent of the time step ranges and of the values of the constants can be independently specified each time a run is restarted, if desired. Obviously it is not necessary to alter the values of these parameters whenever a case is restarted; the ability to do so is merely pointed out. The damping coefficient can be activated at any time by appropriately defining DAMPC, DAMPC1, DAMPI and DAMPI1. In general, it is recommended that the transition from fully damped ($\text{DAMPC} \rightarrow 0$) to completely undamped ($\text{DAMPC1} = 1.0$) be spread over at least 100 time steps (i.e., $\text{DAMPI1} \geq \text{DAMPI} + 100.0$), and that at least 300 time steps be allowed for the initial transient to "wash out" (i.e., $\text{DAMPI} \geq 300$). For example, in a case with an unequal number of blades, suppose that it takes 46 time steps to traverse one blade spacing of the first blade row. DAMPC can be set to 10^{-5} for the first 322 steps, i.e., $\text{DAMPI} = 322.0$. Let the next 92 steps bring the value of the multiplier from 10^{-5} to 1.0 over two time ranges (46 time steps per range). Thus, for the run starting at step number 322 and going to 368: $\text{DAMPC} = 10^{-5}$, $\text{DAMPC1} = .5$, $\text{DAMPI} = 322.0$ and $\text{DAMPI1} = 368.0$. For the run beginning at step number 368: $\text{DAMPC} = .5$, $\text{DAMPC1} = 1.0$, $\text{DAMPI} = 368.0$ and $\text{DAMPI1} = 414.0$. For any subsequent runs the value of the multiplier will be held to 1.0, since the time step will be greater than 414.0.

Options

The program B2DATL is set up to run under a variety of options. The choices available by setting integer flags (see input variables for details) include computational options, input options and output options. The choices and corresponding flags are summarized below.

A. Computational Options

- 1) one or two blade rows (IFØR)
- 2) equal or unequal blade spacing (IBLEQ)
- 3) inclusion or deletion of domains 1 and 7 (IØNE)
- 4) inflow and discharge boundary conditions for the infinite duct approximation, for an open duct, or for acoustic radiation (IBCE)
- 5) include or delete viscous effects (IDELTA)
- 6) blade surface slopes at leading and trailing edge computed from spline fit of surface coordinates, or specified (ISLLE, ISLTE)
- 7) slipstream solutions for upper and lower blades are computed independently or are set equal (ICØR)

B. Input Options

- 1) certain input variables are in dimensional or non-dimensional form (NØNDIM)
- 2) dimensional input (and output) variables are in the International System (MKS) or Customary English (FPS) units system (IDIM)
- 3) restart with new stage geometry or retain previously specified geometry (INEW)
- 4) if the initial flow field is calculated, a linear increase in entropy from rotor leading edge to trailing edge can be included (DELSST)

C. Output Options

- 1) domain output variables in MKS or FPS system (IDIM) (see 2 above)
- 2) domain output variables in non-dimensional or dimensional form (IKP)

- 3) domain output includes virtual grid points for $K = 1, 2, 3, KS+1, KS+2$ and $KS+3$ (LBLADE)
- 4) domain output is printed for specified domains (IDP(ID))
- 5) restart with or without domain or abbreviated output of flow field variables (IPI)
- 6) print of domains at the blade passing frequency or at an independently specified interval (ITAPEØ)
- 7) print corrector values only, or print both predictor and corrector values (ITBUG)

PROGRAM INPUT

Units

Certain input data must be stated in dimensional form, while others may be given in either dimensional or non-dimensional form. (See "Input Options" in previous section.) Those which are dimensional may be given in either the International System (MKS) or Customary English (FPS) units. Two sets of variables are listed below: those which are always dimensional and those which may be non-dimensional. (Non-dimensionalizers are multipliers.)

A. Variables That Are Always Dimensional

<u>Variable</u>	<u>Card No.</u>	<u>MKS</u>	<u>FPS</u>
CE0	14	m	ft
CE1	11	m	ft
CE2	12	m	ft
CE7	14	m	ft
C4	13	m	ft
Y LXLE	11 and 12	radians/m	radians/ft
Y LXTE	11 and 12	radians/m	radians/ft
Y UXLE	11 and 12	radians/m	radians/ft
Y UXTE	11 and 12	radians/m	radians/ft
EX (for blades)	16	m	ft
EX (for AR or BE)	26	m	ft
EY (for blades)	17	radians	radians

<u>Variable</u>	<u>Card No.</u>	<u>MKS</u>	<u>FPS</u>
EY (for AR or BE)	27	m	ft
R (gas constant)	33	(N·m/kg·K)	(ft ² /sec ² °R)
(e.g., for air		287.	1716.)

B. Variables That May Be Non-Dimensional

Variables are non-dimensionalized in the program with respect to the length CE1, the free stream speed of sound $AI = \text{SQRT}(\text{GAMMA} \cdot R \cdot TI)$, a reference temperature $TR = \text{GAMMA} \cdot TI$, and a reference viscosity coefficient $XMUR = PI \cdot CE1 / AI$. The values of CE1, PI and TI are included with input data.

<u>Variable</u>	<u>Card No.</u>	<u>MKS</u>	<u>FPS</u>	<u>Non-Dimensionalizer</u>
ØMG	30	1/sec	1/sec	(CE1/AI)
PI, PC, PFF	30, 32, 35	N/m ²	lbs/ft ²	(1/PI)
TI, TC	30, 35	°K	°R	(1/TR)
UI, UC, UFF, AFF	30, 32, 35	m/sec	ft/sec	(1/AI)
XMU	33	N·sec/m ²	lb _f sec/ft ²	(1/XMUR)
UZ	34	always non-dimensional		(1/AI)

Initial Program Submittal

A blank input form, with headings identifying the variables, is presented in Figure (6). A description of the variables on the data cards are presented in this section. The restart options are discussed in the next section.

<u>Card No.</u>	<u>Columns</u>	<u>Format</u>	<u>Description</u>
1	1-80	20A4	Title card. Any message can be written in the 80 columns of this card; for example, the data set may be identified.
2	1-5	I5	ISTART (0 - original program submittal; 1 - restart case).

1	5	6	10	11	15	16	20	21	25	26	30	31	35	36	40	41	45	46	50	51	55	56	60	61	65	66	70	71	75	76	80
TITLE CARD																															
ISTART	ITAPEØ	IFØR	IØNE	IBCE	IDIM	NØNDIM	IDEBUG	ITBUG	INew																						
IDELTA	NBLADE	LBLADE	IBLEQ	IPI	IKP	ICØR																									
IPXT	IPPT	IPCT	IPHT	IPRT	JPRT																										
IDA	JA	KA	IDB	JB	KB	IDC	JC	KC																							
IDD	JD	KD	IDE	JE	KE	ID6	J6	K6																							
IDC1	JC1	IDC2	JC2	IDC3	JC3	IDC4	JC4	IDC5	JC5	IDC6	JC6																				
IDR1	KR1	IDR2	KR2	IDR3	KR3	IDR4	KR4	IDR5	KR5	IDR6	KR6																				
JS	KS	ISLLE	ISLTE	NØBL	MØBL																										
IDP(1)	IDP(2)	IDP(3)	IDP(4)	IDP(5)	IDP(6)	IDP(7)																									
CE1		YUXLE(1)		YLXLE(1)		YUXTE(1)		YLXTE(1)																							
CE2		YUXLE(2)		YLXLE(2)		YUXTE(2)		YLXTE(2)																							
CE4																															
CE0		CE7																													

FIGURE 6. INPUT FORM

1	5	6	10	11	15	16	20	21	25	26	30	31	35	36	40	41	45	46	50	51	55	56	60	61	65	66	70	71	75	76	80
NSPU(1)		NSPL(1)																													
FIRST BLADE LOWER SURFACE MERIDIONAL COORDINATES EX(1) - EX(NSPU(1))																															
FIRST BLADE LOWER SURFACE CIRCUMFERENTIAL COORDINATES EY(1) - EY(NSPU(1)) (BECOMES YU(1,J))																															
FIRST BLADE UPPER SURFACE MERIDIONAL COORDINATES EX(1) - EX(NSPL(1))																															
FIRST BLADE UPPER SURFACE CIRCUMFERENTIAL COORDINATES EY(1) - EY(NSPL(1)) (BECOMES YL(1,J))																															
NSPU(2)		NSPL(2)																													
SECOND BLADE LOWER SURFACE MERIDIONAL COORDINATES EX(1) - EX(NSPU(2))																															
SECOND BLADE LOWER SURFACE CIRCUMFERENTIAL COORDINATES EY(1) - EY(NSPU(2)) (BECOMES YU(2,J))																															
SECOND BLADE UPPER SURFACE MERIDIONAL COORDINATES EX(1) - EX(NSPL(2))																															
SECOND BLADE UPPER SURFACE CIRCUMFERENTIAL COORDINATES EY(1) - EY(NSPL(2)) (BECOMES YL(2,J))																															

FIGURE 6 (Continued). INPUT FORM

1	5	6	10	11	15	16	20	21	25	26	30	31	35	36	40	41	45	46	50	51	55	56	60	61	65	66	70	71	75	76	80								
NS(1)		NS(2)																																					
MERIDIONAL COORDINATES EX(1) - EX(NS(1)) FOR STREAMSHEET RADIUS																																							
STREAMSHEET RADIUS EY(1) - EY(NS(1)) (BECOMES AR(ID,J))																																							
MERIDIONAL COORDINATES EX(1) - EX(NS(2)) FOR STREAMSHEET THICKNESS																																							
STREAMSHEET THICKNESS EY(1) - EY(NS(2)) (BECOMES BE(ID,J))																																							
ØMG(1)				ØMG(2)				PI				TI				UI				VØUI				DELSSS															
DAMPC				DAMPC1				DAMPI				DAMPI1																											
PFF				AFF				UFF																															
R				GAMMA				REYCR				XMU				CØEFTH				CØEFTE																			
UZ				CDT																																			
PC				TC				UC				VØUC																											

FIGURE 6 (Continued). INPUT FORM

<u>Card No.</u>	<u>Columns</u>	<u>Format</u>	<u>Description</u>
2	6-10	15	ITAPEØ (0 - domain output control defaults to IPRT and JPRT, which are specified on card number 4; 1 - output for domains 1, 2, 3 and 4 is produced automatically at the passing frequency of the second blade row relative to the first, and output for domains 5, 6 and 7 is produced automatically at the passing frequency of the first row relative to the second. IPRT and JPRT are operative regardless of the value assigned to ITAPEØ).
	11-15	15	IFØR (0 - rotor/stator combination; 1 - only one blade row is present, therefore, domains 4 and 5 will be deleted).
	16-20	15	IØNE (0 - include domains 1 and 7; 1 - delete domains 1 and 7).
	21-25	15	IBCE, inlet and discharge boundary condition indicator (1 - infinite duct model (see Equations 93 - 97 of Reference 1); 2 - open duct model (see Equations 87 - 93 of Reference 1); 3 - acoustic far field condition).
	26-30	15	IDIM (1 - input and output in MKS system; 2 - FPS system).
	31-35	15	NØNDIM (0 - dimensional input; 1 - non-dimensional input).
	36-40	15	IDEBUG (0 - value of NBLADE (input #2 on card #3) determines final number of blade passings for run (for unequal numbers of blades); ≠0 - final time step for this submittal (overrides NBLADE)).
	41-45	15	ITBUG (0 - print corrector values only; 1 - print predictor and corrector values).

<u>Card No.</u>	<u>Columns</u>	<u>Format</u>	<u>Description</u>
2	46-50	15	INew (used in conjunction with ISTART = 1) (0 - restart with same stage geometry and previous flow solution N.B. remove cards #15 - #29 from input deck before resubmittal; 1 - restart with specified stage geometry (on cards #15 - #29) but previous flow solution).
3	1-5	15	IDELTA (0 - inviscid solution; 1 - boundary layer and wake solutions are included).
	6-10	15	NBLADE (0 - equal number of blades in each row; $\neq 0$ cumulative number of passings of first blade row at which this run will be terminated. (Must be incremented for every restart.))
	11-15	15	LBLADE (0 - no print of virtual points (e.g., K = 1,2,3) for domain output; 1 - print virtual points in K; 2 - same as 1 plus virtual points in J).
	16-20	15	IBLEQ (0 - same number of blades in rotor and stator, or only one set of blades; 1 - different number of blades in rotor and stator).
	21-25	15	IPI (0 - restart, initial data not printed; 1 - restart, limited debug printout of initial data; 2 - restart, printout of detailed initial data in each domain; 3 - combination of 1 and 2).
	26-30	15	IKP (0 - non-dimensional output; 1 - dimensional output; 2 - both).
	31-35	15	ICØR (0 - sets flow variables at upper slipstream boundary equal to values at lower slipstream boundary in subroutines TRED, SLIP and ØNESID; 1 - compute both boundaries independently). N.B. this parameter is only effective if IBLEQ = 0.

<u>Card No.</u>	<u>Columns</u>	<u>Format</u>	<u>Description</u>
-----------------	----------------	---------------	--------------------

4	<p>N.B. Card #4 is used to specify the intervals at which printout of certain individual grid points, grid columns, grid rows and domains are desired. The points, columns, rows and domains are specified on cards #5, #6, #7, #8 and #10. If a particular type of printout is not desired, set its print interval on card #4 to any number larger than the final time step.</p>		
---	---	--	--

1-5	15	<p>IPXT, print interval for slipstream data output, in number of time steps.</p>	
-----	----	--	--

6-10	15	<p>IPPT, print interval for output of grid points specified on cards #5 and #6, in number of time steps.</p>	
------	----	--	--

11-15	15	<p>IPCT, print interval for output at grid columns specified on card #7, in number of time steps.</p>	
-------	----	---	--

16-20	15	<p>IPHT, print interval for output at grid rows specified on card #8, in number of time steps.</p>	
-------	----	--	--

21-25	15	<p>IPRT, print interval for first blade row domain output (e.g., domains 1, 2, 3 and 4), in number of time steps.</p>	
-------	----	---	--

26-30	15	<p>JPRT - same as IPRT except for second blade row domains (e.g., domains 5, 6 and 7). The domains to be printed at IPRT and JPRT intervals are specified on card #10. This print interval is independent of that specified by ITAPEØ on card #2.</p>	
-------	----	---	--

5-6	<p>Domain identifiers IDA, IDB, IDC, IDD, IDE or ID6 should be left blank or set to zero for that specific point not to be printed. All blanks or zeros imply no individual grid point printout.</p>		
-----	--	--	--

<u>Card No.</u>	<u>Columns</u>	<u>Format</u>	<u>Description</u>
5	1-5	15	IDA, domain number of first individual grid point.
	6-10	15	JA, column number of first individual grid point.
	11-15	15	KA, row number of first individual grid point.
	16-20	15	IDB, domain number of second individual grid point.
	21-25	15	JB, column number of second individual grid point.
	26-30	15	KB, row number of second individual grid point.
	31-35	15	IDC, domain number of third individual grid point.
	36-40	15	JC, column number of third individual grid point.
	41-45	15	KC, row number of third individual grid point.
6	Defines three more individual grid points with the same format as card #5, i.e., IDD, JD, KD; IDE, JE, KE; and ID6, J6, K6.		
7	1-5	15	IDC1, domain number of first individual column.
	6-10	15	JC1, first column number.
	11-15	15	IDC2, domain number of second individual column.
	16-20	15	JC2, second column number.
	21-25	15	IDC3, domain number of third individual column.
	26-30	15	JC3, third column number.
	31-35	15	IDC4, domain number of fourth individual column.
	36-40	15	JC4, fourth column number.
	41-45	15	IDC5, domain number of fifth individual column.
	46-50	15	JC5, fifth column number.
	51-55	15	IDC6, domain number of sixth individual column.
	56-60	15	JC6, sixth column number.
8	Defines six individual rows for output with the same format as card #7, i.e., IDR1, KR1, . . . , IDR6, KR6.		

<u>Card No.</u>	<u>Columns</u>	<u>Format</u>	<u>Description</u>
9	1-5	I5	JS, number of meridional mesh columns plus 1, in each domain. (Presently max JS=18).
	6-10	I5	KS, number of circumferential mesh rows, plus 3, in each domain. (Presently max KS=12).
	11-15	I5	ISLLE, leading edge indicator (0 - spline fit of blade coordinates determines the leading edge slopes; 1 - leading edge slopes specified on cards #11 and #12).
	16-20	I5	ISLTE, trailing edge indicator (0 - spline fit determines trailing edge slopes; 1 - trailing edge slopes specified on cards #11 and #12).
	21-30	I5	NØBL, number of blades in first row.
	31-35	I5	MØBL, number of blades in second row. (N.B. $1 \leq (MØBL/NØBL) \leq 3/2$).
10	If no domain output desired card #10 may be blank.		
	1-5	I5	IDP(1)
	6-10	I5	IDP(2)
	11-15	I5	IDP(3) flags for output in domain 1 to 7
	16-20	I5	IDP(4) (0 - delete complete output for this
	21-25	I5	IDP(5) domain; 1 - domain output for this
	26-30	I5	IDP(6) domain is desired)
	31-35	I5	IDP(7)
11-12	The slopes specified on cards #11 and #12 are necessary if the associated leading edge indicator ISLLE (input #3 on card #9) or trailing edge indicator ISLTE (input #4 on card #9) is set equal to 1.		
11	1-10	E10.0	CE1, meridional length of first blade row; m.
	11-20	E10.0	YUXLE(1), lower surface leading edge slope for first blade row (upper boundary of domain 3); rad/m.
	21-30	E10.0	YLXLE(1), upper surface leading edge slope for first blade row (lower boundary of domain 3); rad/m.

<u>Card No.</u>	<u>Columns</u>	<u>Format</u>	<u>Description</u>
11	31-40	E10.0	YUXTE(1), lower surface trailing edge slope for first blade row (upper boundary of domain 3); rad/m.
	41-50	E10.0	YLXTE(1), upper surface trailing edge slope for first blade row (lower boundary of domain 3); rad/m.
12	Defines same data as card #11 with same format except data is for second blade row i.e., CE2, YUXLE(2), YLXLE(2), YUXTE(2) and YLXTE(2). If there is no second row, columns 1-10 on card #12 equal columns 1-10 on card #11, and rest of card may be left blank. (N.B. CE2 must equal CE1 for a single blade row (IFØR = 1) i.e., domains 4 and 5 are deleted.)		
13	1-10	E10.0	C4, meridional length of inter-blade row domain; m. (If there is only one blade row, C4=first blade row meridional length = CE1.)
14	1-10	E10.0	CE0, meridional length of domain 1; m.
	11-20	E10.0	CE7, meridional length of domain 7; m.
	N.B. if IØNE = 1, CE0 and CE7 must equal first blade row meridional length = CE1.		
15-19	Cards #15 - #19 define the upper and lower blade surfaces for the first blade row. If restarting the program with INEW=0 (input #10 on card #2) , omit these cards from input deck.		
15	1-5	15	NSPU(1), number of data points defining upper boundary of domain 3 (lower surface of first blade row). (max=36)
	6-10	15	NSPL(1), number of data points defining lower boundary of domain 3 (upper surface of first blade row). (max=36)
16	1-10	E10.0	EX(1), meridional coordinates of data points defining lower blade surface; m.

<u>Card No.</u>	<u>Columns</u>	<u>Format</u>	<u>Description</u>
16	11-20	E10.0	EX(2) (N.B. eight values to a card, continue on subsequent cards with same format. Origin of blade coordinates is the leading edge, i.e., EX(1) = 0.0.)
	.	.	.
	.	.	.
	.	.	.
	.	E10.0	EX(NSPU(1))
17	1-10	E10.0	EY(1), circumferential coordinates
	11-20	E10.0	EY(2), defining lower blade surface, where EY(1)=0 (origin is the leading edge of the blade); radians.
	.	.	.
	.	.	.
	.	.	.
	.	E10.0	EY(NSPU(2))
18-19	Cards #18 and #19 define the upper blade surface in the same format as cards #16 and #17.		
20-24	Cards #20 - #24 define the lower and upper blade surfaces for the second blade row in the same format as cards #15 - #19. Origin of coordinate system is the leading edge of second blade row. If there is no second row, or if restarting program with INEW=0 (input #10 on card #2), omit these cards from input deck.		
25-29	Cards #25 - #29 define the streamsheet radius and thickness. If restarting program with INEW=0 (input #10 on card #2), omit these cards from input deck.		
25	1-5	I5	NS(1), number of data points defining streamsheet radius (max=36).
	6-10	I5	NS(2), number of data points defining streamsheet thickness (max=36).
26	1-10	E10.0	EX(1), meridional coordinates of data points
	11-20	E10.0	EX(2), defining streamsheet radius, where EX=0 at J=2 in domain 2 (i.e., origin of this coordinate system is a distance CE1 upstream of first blade row); m.
	.	.	.
	.	.	.
	.	.	.
	.	E10.0	EX(NS(1))

<u>Card No.</u>	<u>Columns</u>	<u>Format</u>	<u>Description</u>
27	1-10	E10.0	EY(1), radial coordinates of data points
	11-20	E10.0	EY(2), defining streamsheet radius; m. (These
	.	.	coordinates are converted to AR(1D,J)).
	.	.	.
	.	E10.0	EY(NS(1))
28-29	Cards #28 and #29 define the streamsheet normal thickness in the same format as cards #26 - #27. (These coordinates are converted to BE(1D,J)).		
30	1-10	E10.0	ØMG(1), angular velocity of first blade row (Rad/sec). (Negative for clockwise rotation; see Figure 2.)
	11-20	E10.0	ØMG(2), angular velocity of second blade row (Rad/sec). (ØMG(2) - ØMG(1) \geq 0 is required.)
	21-30	E10.0	PI, inlet static pressure; N/m ² .
	31-40	E10.0	TI, inlet static temperature; K.
	41-50	E10.0	UI, inlet meridional velocity; m/sec.
	51-60	E10.0	VØUI, ratio of inlet circumferential velocity (in absolute coordinates) to inlet meridional velocity. (Negative in clockwise direction, see Figure 2.)
	61-70	E10.0	DELS _{SS} , increase in non-dimensional entropy ($\Delta S/C_v$) between inflow and outflow boundaries to be included in initial data. (Usually = 0.)
31	1-10	E10.0	DAMPC, coefficient that multiplies slipstream velocity for time steps from 0 to DAMPI (input #3 card #31).
	11-20	E10.0	DAMPC1, coefficient that multiplies slipstream velocity for time steps from DAMPI1 (input #4 card #31) to end of case.
	21-30	E10.0	DAMPI, time step number that terminates usage of DAMPC coefficient as slipstream multiplier.
	31-40	E10.0	DAMPI1, time step number that initiates usage of DAMPC1 coefficient.

N.B. Between time steps DAMPI and DAMPI1 the coefficient that multiplies slipstream velocity varies from DAMPC to DAMPC1 using a cosine curve.

<u>Card No.</u>	<u>Columns</u>	<u>Format</u>	<u>Description</u>
32	1-10	E10.0	PFF, discharge static pressure; N/m^2 .
	11-20	E10.0	AFF, speed of sound at discharge station, m/sec.
	21-30	E10.0	UFF, meridional velocity at discharge station; m/sec.
33	1-10	E10.0	R, gas constant; $N \cdot m/kg \cdot K$.
	11-20	E10.0	GAMMA, ratio of specific heats.
	21-30	E10.0	REYCR, transition Reynolds number. (Criterion used for transition from laminar to turbulent boundary layer analysis.)
	31-40	E10.0	XMU, dynamic viscosity; $N \cdot sec/m^2$.
	41-50	E10.0	CØEFTH, weighting factor for averaging stream-line angle and surface angle at leading edge (range of 0.0 to 1.0, recommended value is 1.0). See Reference (1), Equation (141).
	51-60	E10.0	CØEFTE, weighting factor for averaging slipstream angle and surface angle at trailing edge (range of 0.0 to 1.0, recommended value is .6667). See Reference (1), Equation (140).
34	1-10	E10.0	UZ, non-dimensional magnitude of largest total velocity vector anticipated in flow field (used in estimating minimum value of CFL stability criterion.) Non-dimensionalized with respect to free-stream speed of sound; see "Units" sub-section above.
	11-20	E10.0	CDT, time step multiplier for CFL stability criterion (recommended range is $1 \leq CDT \leq 3$).
35	The following card describes the flow field for an initial run only. Only one card is necessary to define initial conditions. The inlet values PI, TI, UI and VUØI are appropriate selections, but other values may be used.		
	1-10	E10.0	PC, static pressure; N/m^2 .
	11-20	E10.0	TC, static temperature; K.

<u>Card No.</u>	<u>Columns</u>	<u>Format</u>	<u>Description</u>
35	21-30	E10.0	UC, meridional velocity, m/sec.
	31-40	E10.0	VØUC, ratio of absolute circumferential velocity to meridional velocity.

Restarting the Program

In general, scratch files identified as TAPE1, TAPE2, TAPE3, TAPE4, TAPE8 and TAPE9 must be allocated to the program, although not all will necessarily be used. TAPE9 is an (unformatted) output file which is written at the normal termination of a run, for possible use in restarting the run. It contains the flow solution at all grid points. TAPE8 is an (unformatted) input file from which the data stored as TAPE9 can be read to restart a run. TAPE1, TAPE2, TAPE3 and TAPE4 are only used when running a stage having an unequal number of blades in the two blade rows. In this case, these four files are used as external storage devices, as well as to provide time-phased boundary data needed to restart a run. When an even number of passings of the first blade row is completed, e.g., NBLADE = 2,4,6 etc., then the required data will be on TAPE1 and TAPE2. When an odd number of passings is completed, the data will be on TAPE3 and TAPE4. In either event, TAPE1 and TAPE2 will serve as the input files for the time-phased boundary data. Use of these files is summarized below:

TAPE1 and TAPE2 - input files for time-phased boundary data. Also used as scratch files for time-phased boundary data during a run, and should be saved to restart the run if it terminates after an even number of blade passings (i.e., NBLADE = 2,4,6, etc.).

TAPE3 and TAPE4 - scratch files similar to TAPE1 and TAPE2, but never used as the input files when restarting a run. These files should be saved to restart a run if it terminates after an odd number of blade passings (i.e., NBLADE = 1,3,5, etc.) In this case these files must be identified as TAPE1 and TAPE2 when restarting the run.

TAPE8 - an unformatted input file, containing the flow solution at all grid points, used to initialize the problem when restarting a run.

TAPE9 - an unformatted output file, written at the normal termination of a run, which provides the data for TAPE8.

To restart the program, input cards 1 through 34 are necessary with the following changes. Input variable ISTART (card #2, input #1) must be set to 1. The final time step for this run must be set either by IDEBUG (card #2, input #8) or NBLADE (card #3, input #2). If restarting with the same blade and streamsheet geometry, i.e., INEW = 0 (card #2, input #10), cards #15 through #29 are removed from the input deck. It may be desirable to change some other inputs such as the title card, INEW (card #2, input #10), IDELTA (card #3, input #1), LBLADE (card #3, input #3), IPI (card #3, input #5), IKP (card #3, input #6), print options on cards #4 - #8 and card #10, and/or slipstream velocity damping coefficients and range values on card #31. In addition, if a case has converged to an asymptotic solution and it is now desirable to display dimensional output rather than non-dimensional values, for example, a restart run can be submitted where either IDEBUG = final time step of last run, or NBLADE = same value as last submittal, and IPI = 2, IKP = 1, IPRT = 1 and JPRT = 1.

Because of present restrictions to the program, no restarts can be made with changes to the variables OMG(1), OMG(2), or VOUL.

Sample Input

A sample input form is presented in Figure (6). Appendix A includes the first few pages of a typical program output which displays the input data in card image format with the appropriate headings.

PROGRAM OUTPUT

A sample printout from Program B2DATL is presented in Appendix A, and may be referred to in connection with the following discussion. The output is arranged in four sections: input data, initial data and constants derived from the input data, intermediate output, and domain output. Domain output which is dimensional is printed with the appropriate units in the heading; units for variables appearing in the other sections are given below.

Input Data

The input data is printed in card image format with headings corresponding to those on the input form (Figure 6). This data has been described in the previous section.

Initial Data and Constants

The initial block of computed data consists of geometric boundary data, i.e., definition of the blade and streamsheet parameters at the grid points, and general constants derived from the input data. It is only printed once at the beginning of each case, i.e., on the initial submittal run.

- J1 ARRAY - Values of J index of first interior grid column of each domain.
- JF ARRAY - Values of J index of last interior grid column of each domain.
- ES1 - Angular distance between leading edges of first blade row; rad.
- ES2 - Angular distance between leading edges of second blade row; rad.
- TIME - Initial value of non-dimensional elapsed time (time in seconds = $TIME \cdot CE1/A1$).
- PI - Value of static pressure used in non-dimensionalization; N/m^2 .
- A1 - Value of speed of sound used in non-dimensionalization; m/sec.
- TR - Value of static temperature used in non-dimensionalization; K.
- XMUR - Value of viscosity coefficient used in non-dimensionalization; $N \cdot sec/m^2$.
- ITIMEF - Total number of time steps to be computed.
- DX - Non-dimensional grid spacing in the meridional direction, $\Delta\sigma$.
(See Reference 1, Equation 57.)
- DN - Non-dimensional grid spacing in the circumferential direction, Δv .
(See Reference 1, Equation 58.)
- DT - Non-dimensional time step, $\Delta\tau$. (See Reference 1, Equation 69.)
- J - Grid column index.
- YU - Non-dimensional angular coordinate of upper boundary of domain, i.e.; lower surface of upper blade ($\theta_{u1}/ES1$ or $\theta_{u2}/ES2$).
- YL - Non-dimensional angular coordinate of lower boundary of domain, i.e.; upper surface of lower blade ($\theta_{l1}/ES1$ or $\theta_{l2}/ES2$).

- YUX - Derivative of YU with respect to non-dimensional meridional distance, σ (e.g., $d\theta/d\sigma/ES1$).
- Y LX - Derivative of YL with respect to non-dimensional meridional distance, σ .
- AR - Non-dimensional streamsheet radius ($r/CE1$).
- BE - Non-dimensional streamsheet thickness ($b/CE1$).
- ARX - Derivative of AR with respect to non-dimensional meridional distance, σ .
- BEX - Derivative of BE with respect to non-dimensional meridional distance, σ .

On a restart run, the following data is printed in this section:

- IDL1Ø2 - An index identifying blade rows 1 and 2. ($IDL1Ø2 = (ID-1)/2$).
- DSU(3) - Non-dimensional displacement thickness along upper boundary, i.e.; lower surface of upper blade (corrector value).
- DSU(2) - Same as DSU(3) (predictor value).
- DSL(3) - Non-dimensional displacement thickness along lower boundary, i.e.; upper surface of lower blade (corrector value).
- DSL(2) - Same as DSL(2) (predictor value).

Intermediate Output

Data printed in this section consists of flow variables at selected grid points, columns and rows, and slipstream information, at the specified time intervals, in accord with input data on cards #4, #5, #6, #7, #8 and #10. The variables printed in this section are:

- ITIME - Current value of time step counter.
- PHILE(I,L) - Streamline angle at leading edge of lower blade of I^{th} row, at time step $ITIME-3+L$; radians.
- PHITE(I,L) - Slipstream angle at trailing edge of lower blade of I^{th} row, at time step $ITIME-3+L$; radians.
- PHILP(I,L) - Same as PHILE(I,L), but in reference to upper blade.
- PHITP(I,L) - Same as PHITE(I,L), but in reference to upper blade.

- PHIEX(L) - Angle between slipstream of lower blade and the meridional direction at the discharge boundary, at time step $ITIME-3+L$; radians.
- PHIEY(L) - Same as PHIEX(L), but in reference to the upper blade.
- YSL(I,J,3) - Circumferential coordinate of slipstream of lower blade of the I^{th} row, at the J^{th} grid column and at time step $ITIME$, in a coordinate system attached to the I^{th} blade row; m.
- YSXL(I,J,3) - Derivative of YSL with respect to meridional coordinate, x .
- VSAY(I,J) - Non-dimensional velocity of slipstream, \bar{v} , of lower blade of I^{th} row, at J^{th} grid column and at time step $ITIME$.
(See Reference 1, Equation 134.)
- YSU(I,J,3) - Same as YSL, but with respect to upper blade.
- YSXU(I,J,3) - Derivative of YSU with respect to meridional coordinate, x .
- VSAYP(I,J) - Same as VSAY(I,J), but in reference to upper blade.
- ID,J,K - Domain, grid column and grid row indices, for specified grid point printout, from card #5.
- P - Non-dimensional static pressure (p/P_1).
- R - Non-dimensional static density ($\rho \cdot A_1^2/P_1$).
- U - Non-dimensional meridional component of velocity (u/A_1).
- V - Non-dimensional (relative) circumferential component of velocity (v/A_1).
- E - Non-dimensional (relative) total internal energy (E'/A_1^2).
- IDC1, JC1 - Domain and grid column indices for 1st set of columnar output, from card #7. (Depending on input data, up to 6 sets of column output for time step $ITIME$ may be printed.)
- IDR1, KR1 - Domain and grid row indices for 1st set of row output, from card #8. (Depending on output data, up to 6 sets of row output for time step $ITIME$ may be printed.)

Domain Output

The section contains the principal statement of the flow solution at a selected time step. The output is arranged by grid columns, beginning with the first domain and proceeding to the last. (Domains not used in a particular case are, of course, deleted.) The solution at a particular grid row is tabulated first in non-dimensional form, in ascending order of the row index K (i.e.,

proceeding from the bottom of the domain to the top). If dimensional output is requested (IKP = 1), a second tabulation is printed for each column. In this section, all dimensional variables are identified by the appropriate units in the printed heading, and all non-dimensional variables are identifiable by the absence of units in the heading. The variables appearing in this section are defined as follows (where it is understood that the term relative only applies in those domains attached to a rotating blade row):

- ITIME - Time step counter.
- TIME - Elapsed time since run was initiated. ($ITIME \cdot \Delta T \cdot AI / CE1$.)
- ID - Domain index.
- J - Grid column index.
- X - Meridional distance (measured from a station located one meridional chord length, CE1, upstream of the first blade row); m.
- MDOT - Weight flow rate crossing the passage at the J^{th} column; kg/sec.
- K - Grid row index.
- Y - Circumferential coordinate of grid point, in an absolute frame of reference defined at initiation of the run; m or radians.
- P - Static pressure, p. (Non-dimensional, $p/P1$, or dimensional, N/m^2 .)
- RHO - Static density, ρ . (Non-dimensional, $\rho \cdot AI^2 / P1$, or dimensional, kg/m^3 .)
- U - Meridional component of velocity, u. (Non-dimensional, u/AI , or dimensional, m/sec.)
- V - Relative circumferential component of velocity, v. (Non-dimensional, v/AI , or dimensional, m/sec.)
- E - Relative total internal energy, E' . (Non-dimensional, E'/AI^2 .)
- T - Static temperature. (Non-dimensional, T/TR , or dimensional, K.)
- H - Relative total enthalpy, H' . (Non-dimensional, H'/AI^2 .)
- M - Relative Mach number.
- S - Non-dimensional entropy rise $((S - S_{\infty}) / C_v)$.

The following variables only appear in the optional printout obtained with IKP=1:

- Q - Magnitude of the relative velocity vector, \vec{V} ; m/sec.
- BETA - Angle between the relative velocity vector, \vec{V} , and the meridional direction; radians.

PT - Absolute total pressure; N/m^2 .

STREAM

FNCT - The integral of the weight flow rate from $K=4$ to the K^{th} grid point divided by $MDOT$, at the J^{th} grid column. In domains 1 and 2, the lower limit of the integral is a meridional plane (i.e., $\theta=constant$) intersecting the leading edge of the lower blade of the first row, rather than the grid row $K=4$. In a steady flow, lines of constant STREAM FNCT are streamlines.

The slipstream information included in the "Intermediate Output" section, i.e., YSL, YSXL, VSAY, etc., pertaining to domains 4, 6 and 7 are also printed following the domain output for each of these sections.

Normal termination of a run is indicated by the message "TAPE9 IS WRITTEN". As discussed in the section "Restarting the Program", this file may be saved to continue the run from the last time step.

PROGRAM STRUCTURE

Flow Chart of Overall Program

The program starts in B2DATL which calls UNCOM2. No return to B2DATL occurs. All other called routines return to the calling routine. The program exits from UNCOM2. A flow chart for the overall program operation is shown in Figure (7).

Individual Routine Flow Charts

The flow charts of the main routine, B2DATL and subroutine UNCOM2 are shown on Figures (8) and (9). Flow charts of all other routines have not been included because they follow virtually "straight through" paths which are self evident.

Description of Subroutines

<u>Name</u>	<u>Description</u>
B2DATL	Reads initial data, computes blade shapes and streamsheet geometry, calculates mesh size, computes time step, and initializes all variables.

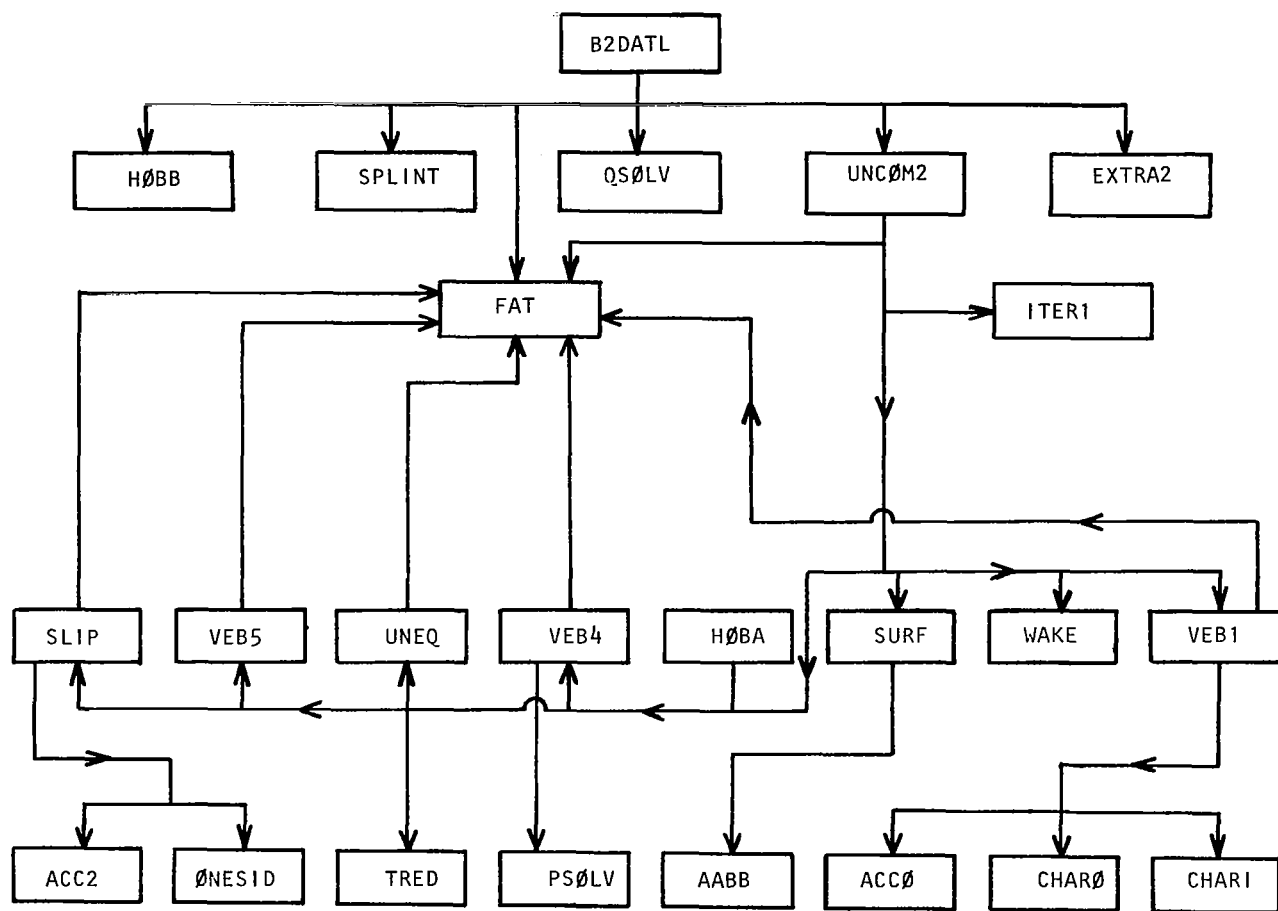


FIGURE 7. - CALLING RELATIONSHIP OF SUBROUTINES IN PROGRAM B2DATL.

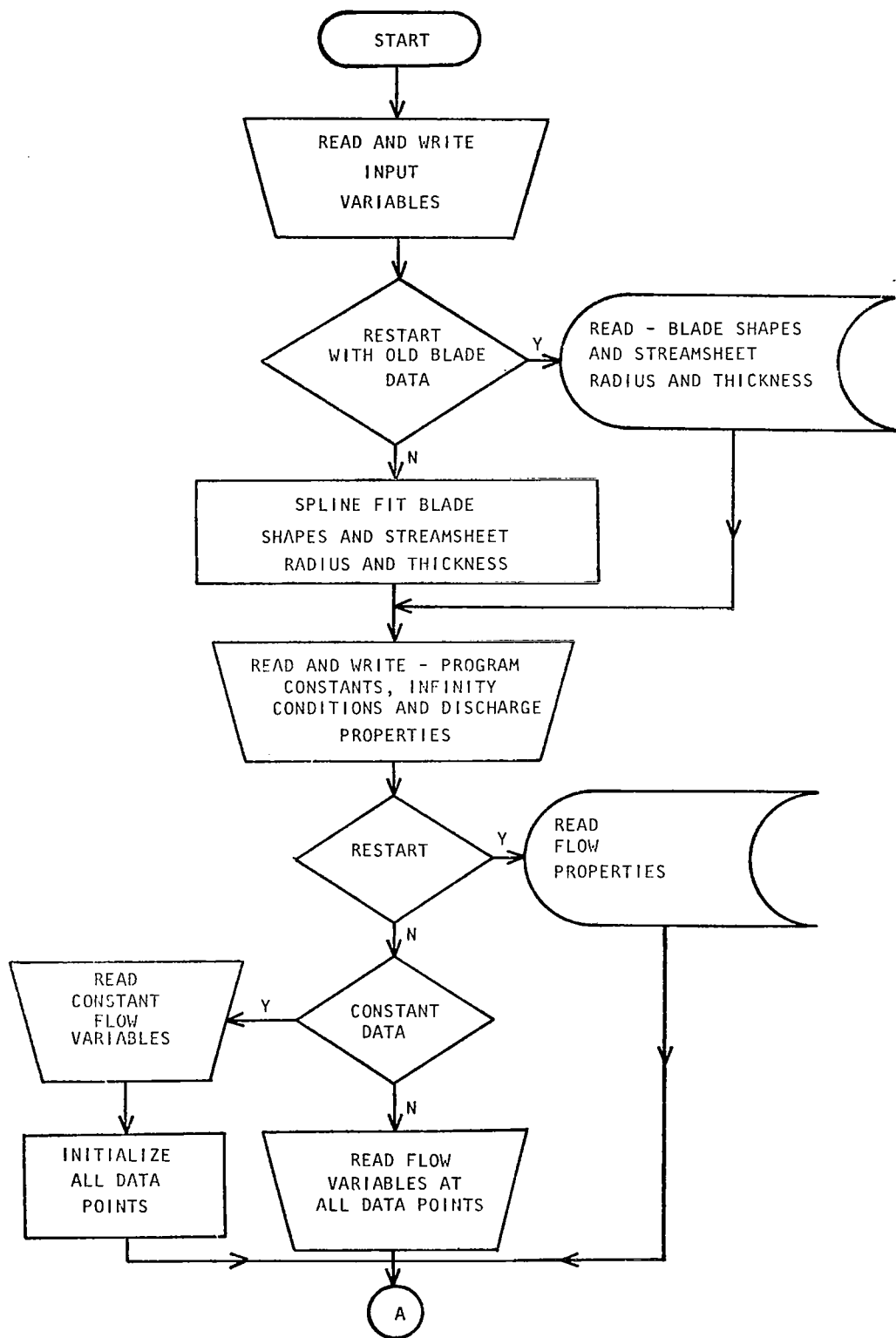


FIGURE 8. FLOW CHART OF MAIN ROUTINE B2DATL

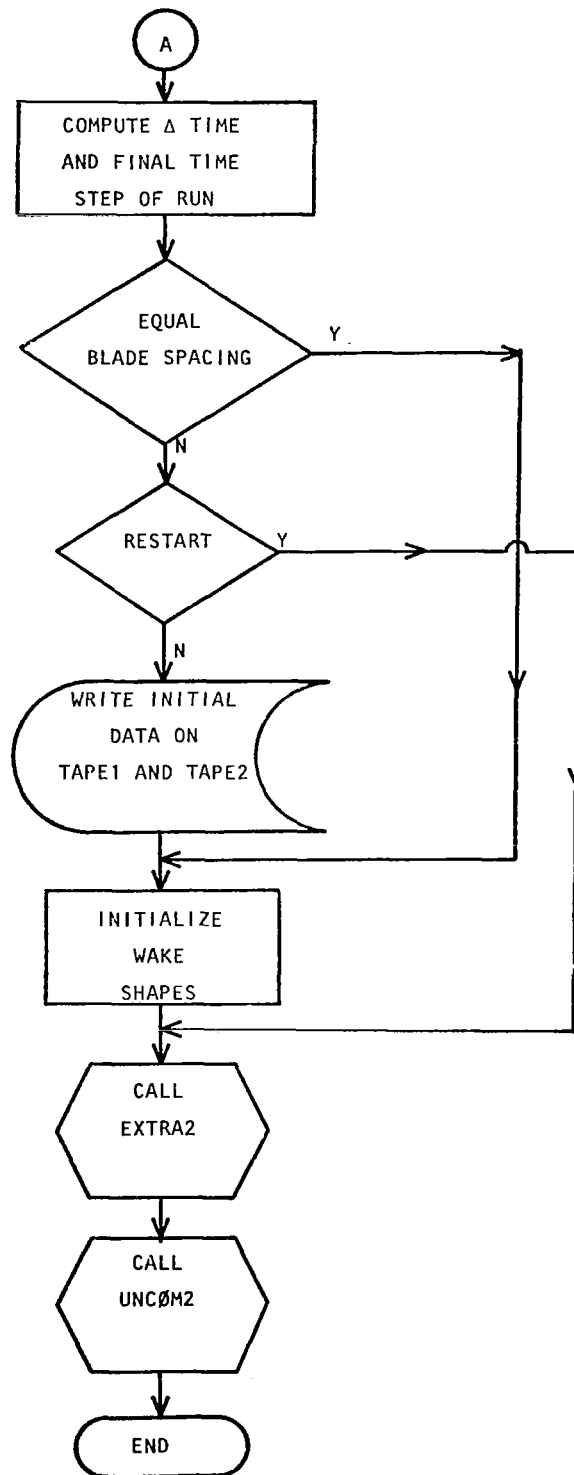


FIGURE 8(Continued). FLOW CHART OF MAIN ROUTINE B2DATL.

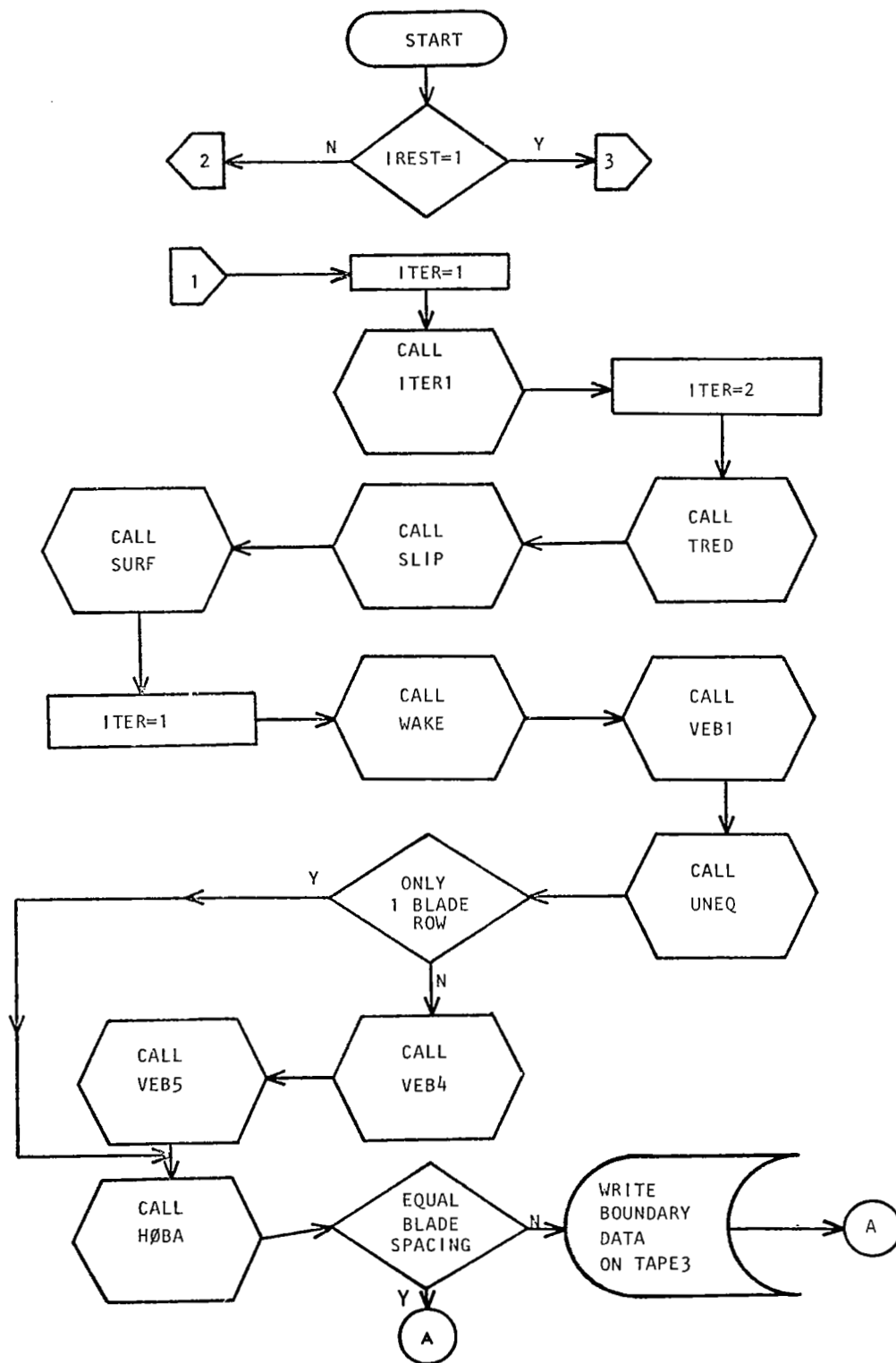


FIGURE 9. FLOW CHART OF SUBROUTINE UNCØM2

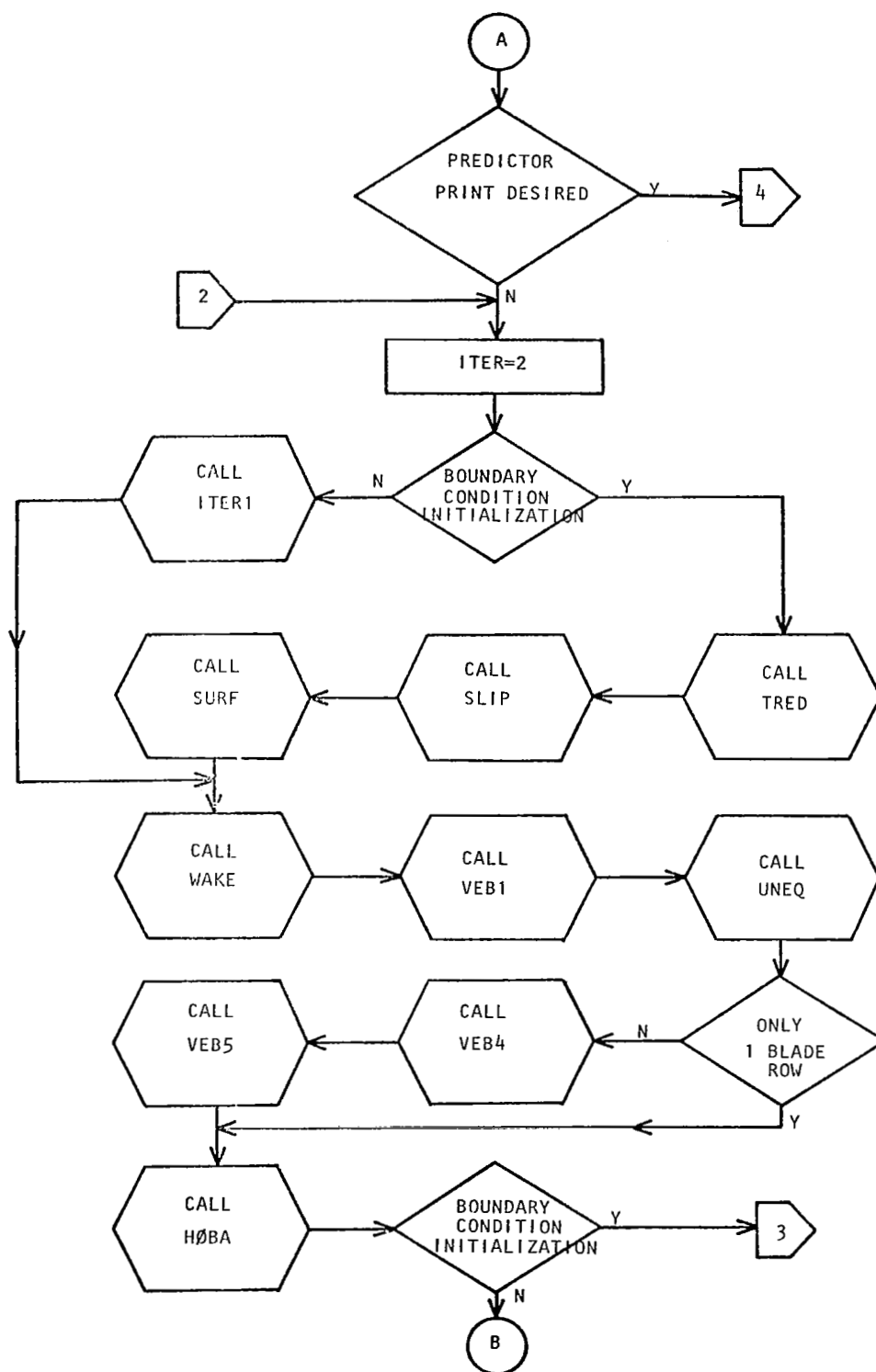


FIGURE 9(Continued). FLOW CHART OF SUBROUTINE UNCØM2

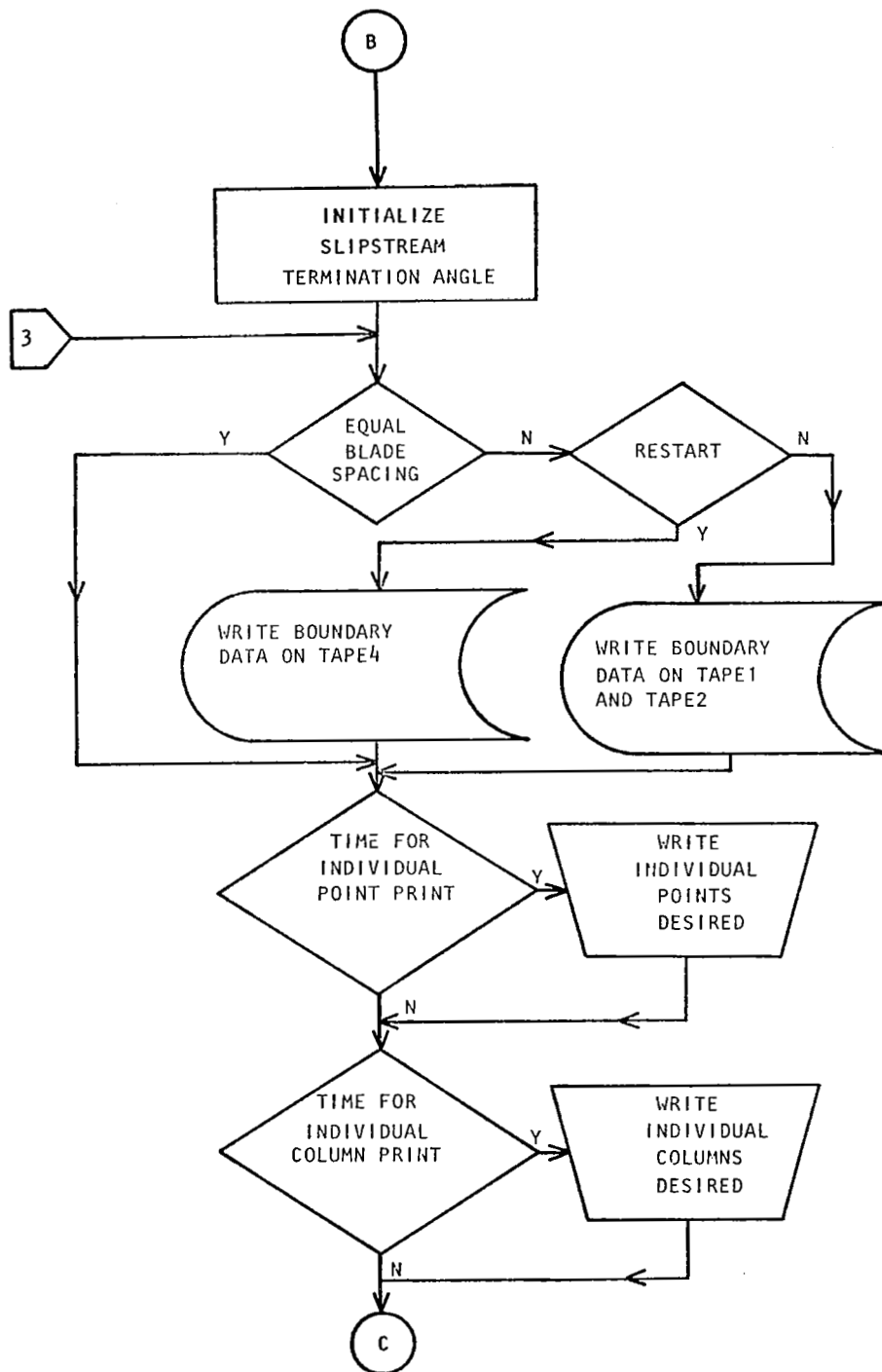


FIGURE 9(Continued). FLOW CHART OF SUBROUTINE UNCOM2

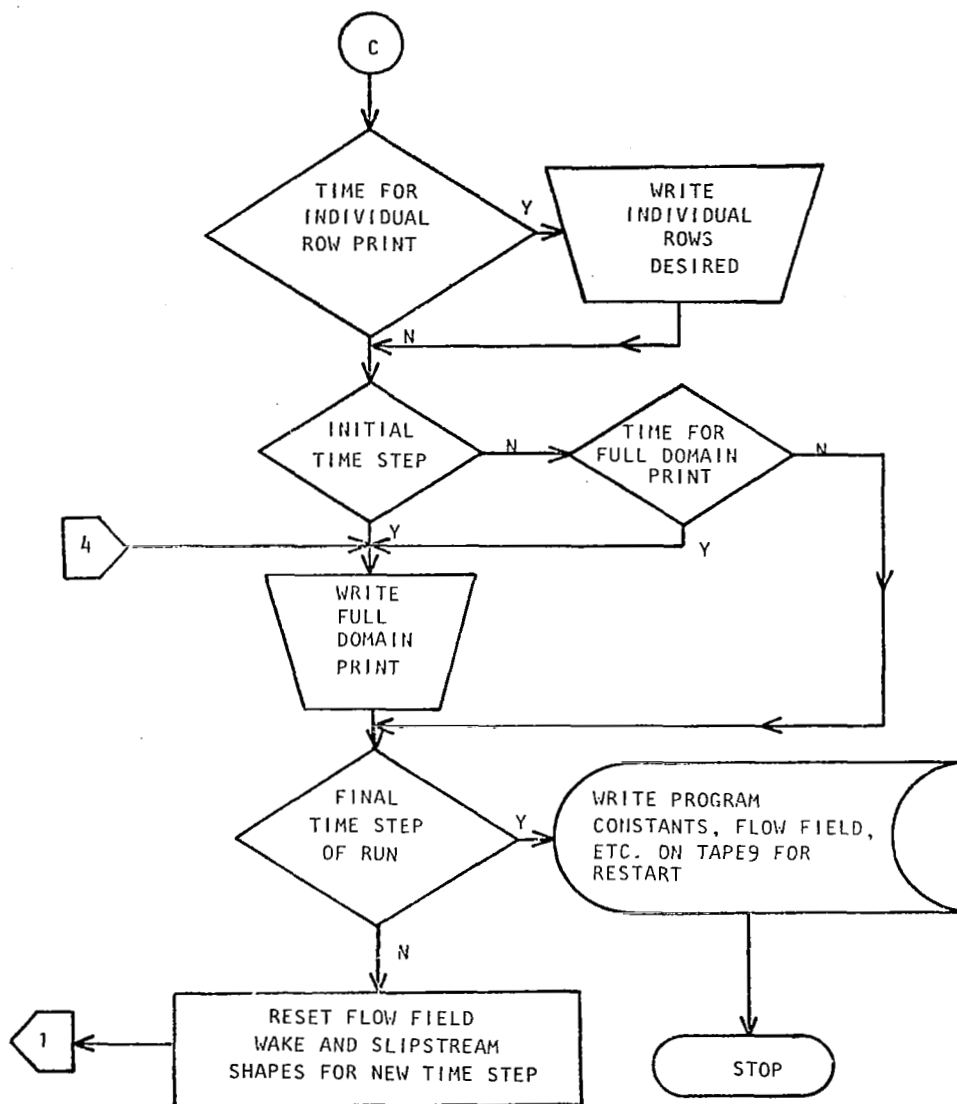


FIGURE 9(Continued). FLOW CHART OF SUBROUTINE UNCØM2

<u>Name</u>	<u>Description</u>
UNCØM2	Calls other routines for interior and boundary point calculations, advances the time step, writes program variables on disk file for restart and writes normal program output.
ITER1	Advances interior grid point solution from time "t" to "t+Δt", by MacCormack algorithm. (See Reference 1, Equations 64 to 68.)
TRED	Evaluates flow properties at the leading and trailing edge of blades, namely at $(ID,J,K) = (2,12,K), (3,2,K), (3,JS,K), (4,2,K), (5,2,K), (5,JS,K)$ and $(6,2,K)$, where $K = 3, 4, KS$ and $KS+1$. TRED also evaluates two special points called the "A" points at the leading edge of the blades in domain 5 (see Reference 1, Figure 9b). The values are stored at $P15(I), R15(I), U15(I)$ and $V15(I)$ where $I = 1$ for the lower boundary, i.e., $K = 4$, and $I = 2$ for the upper boundary, i.e., $K = KS$. These points bear the same relationship to domain 5 as points $(2,JS,K)$ with $(K = 4 \text{ or } K = KS)$ bear to domain 3, and are used for evaluating the boundary conditions in VEB4 (discussed later). TRED also defines the streamline angles PHILE, PHILP, PHITE and PHITP at the leading edges and trailing edges. (See Reference 1, Equations 140 and 141.)
SURF	Evaluates the flow properties on the upper and lower blade surfaces i.e., at (ID,J,K) where $ID = 3 \text{ or } 5$ and $K = 4 \text{ or } 12$, and J varies from 3 to $JS - 1$. (See Reference 1, Equations 129 to 132d.)
SLIP	Computes the slipstream shapes and the flow properties along the upper and lower slipstreams at time $t+\Delta t$. This routine handles the grid points (ID,J,K) where $ID = 4, 6$ and 7 ; $K = 3, 4, KS$ and $KS+1$; and J varies from 3 to $JS-1$ (or to JS in domain 6 when domain 7 is active). SLIP also defines the slipstream motion at the new time. (See Reference 1, Equations 133 - 137b.) In the case of equal numbers of blades or a single blade row, only the lower slipstream solution is normally obtained, and the upper slipstream solution is equated to the lower one ($ICØR = 0$). For the case of unequal numbers of blades the upper and lower solution are evaluated independently.

<u>Name</u>	<u>Description</u>
ØNESID	Performs the same operation as SLIP for the last points on the slipstream in domain 4 and domain 6 (if 7 is inactive) or domain 7 (if domain 7 is active); namely, at (ID,JS,K) where ID is 4, 6 or 7 as specified above and K is the same as defined in SLIP. ØNESID also defines the slipstream motion at the intersection with the discharge boundary. (See discussion in Reference 1.)
WAKE	Calculates blade wake properties, i.e., u_m , H'_m , δ and δ_T . (See Reference 1, Equations 205, 206, 208 and 214, or 225 to 229.)
VEB1	Evaluates all vertical boundaries other than those done by VEB4 and VEB5, by equating or interpolating data in adjacent domains, except the inlet boundary, i.e., (ID,J,K) = (1,2,K) if domain 1 is active, or (2,2,K) if domain 1 is deleted, and the discharge boundary, i.e., (ID,J,K) = (7,JS,K) if domain 7 is active or (6,2,K) if domain 7 is deleted. The inlet boundary solution is performed by subroutine CHAR1 and the discharge boundary solution is performed by CHARØ, both of which are called by VEB1. Specifically, VEB1 sets the following (ID,J,K) boundary values: (2,JS,K) = (3,2,K), (4,2,K) = (3,JS,K) and (6,2,K) = (5,JS,K), except for points evaluated by TRED; (3,1,K) = (2,JS-1,K), (5,JS+1,K) = (6,3,K); and if domains 1 and 7 are active, (2,1,K) and (6,JS+1,K) are interpolated from within domains 1 and 7 respectively. If domains 1 and 7 are deleted, CHAR1 and CHARØ, discussed earlier, evaluate (2,2,K) and (6,JS,K); (3,JS+1,K) is interpolated from between (4,JLE,K) and (4,JLE+1,K) if domain 4 is active or (3,JS+1,K) = (6,2,K) if domain 4 is deleted. (N.B. for the latter CE2 = CE1.)
UNEQ	Retrieves data from TAPE1, TAPE2, TAPE3 and TAPE4 as needed for time-phased boundary conditions in cases with unequal numbers of blades in the two blade rows.

<u>Name</u>	<u>Description</u>
VEB4	Evaluates the properties on the vertical outflow boundary of domain 4, i.e., $(ID,J,K) = (4,JS,K)$ where K varies from 5 to $KS - 1$.
VEB5	Evaluates the properties on the vertical, virtual inflow boundary of domain 5, i.e., $(ID,J,K) = (5,1,K)$, based on linear interpolation of the interior solution of domain 4 at the same physical locations.
HØBA	Equates exterior grid point solutions, at the points (ID,J,K) for all ID, all J, and $K = 1, 2, KS+2$, and $KS+3$, to corresponding interior point solutions. In addition, the same operation is performed for subset $K = 3$ and $KS+1$ at those boundaries not evaluated by TRED, SLIP and ØNESID.
CHARI	Imposes inlet boundary conditions and performs inlet station solution by method-of-characteristics (called by VEB1). (See Reference 1, Equations 87 to 97.)
CHARØ	Imposes discharge boundary conditions and performs discharge station solution by method-of-characteristics (called by VEB1). (See Reference 1, Equations 98 to 108.)
ACCØ	Performs inlet and discharge station boundary conditions by acoustic far field analysis. (Presently a dummy routine, which may be replaced by coding contained in Reference 2.)
HØBB	Spline fit interpolation routine which uses a specified first derivative as the end-point condition.
SPLINT	Spline fit interpolation routine which uses the end-point condition that the second derivative at either end-point is one-half that of the next spline point.
FAT	Performs linear interpolation of variables.
QSØLV	Solves for pressure, given the values of ρu , ρuH , $\rho u^2 + p$, and v/u .

<u>Name</u>	<u>Description</u>
PSØLV	Solves for pressure, given the values of ρu , $\rho u^2 + p$, v and H .
AABB	Solves for AA and BB used in boundary layer computations, i.e., $\partial \delta^*/\partial x = AA(Re)^{-BB}$. (See Reference 1, Equations 170 to 174.)
EXTRA2	A dummy routine which can be used to replace elements of the initial data read from TAPE8 on a restart run. Requires recompilation of EXTRA2 with appropriate FØRTRAN statements to define those variables which the user wants to alter.
ACC2	Interpolates slipstream location for new time step at the grid column positions. (See Reference 1, Equations 138 and 139.)

Dictionary Of Principal Variables

The principal FØRTRAN variables are defined below. The present dimensions permit analysis of 7 domains with up to 19 grid columns and 15 grid rows (including exterior or virtual points) in each domain. In general, a dimension of 2 indicates reference to the two blade rows. In the case of triply subscripted variables, a 3 in the first subscript refers to the three domains in which slipstreams occur (i.e., 1 denotes domain 4, 2 denotes domain 6 and 3 denotes domain 7), while a 3 in the last subscript refers to (1) the initial value, (2) the predictor value, and (3) the corrector value. A dimension of 9 is used in connection with the time-phased boundary conditions. A dimension of 19 refers to the maximum number of grid columns, and 15 to the maximum number of grid rows. The last two values represent the only two dimensions which need to be increased to permit use of a finer grid spacing; the routines and common blocks which must be changed to accomplish this are listed in Appendix B.

<u>Name</u>	<u>Dimension</u>	<u>Common</u>	<u>Definition</u>
AR	(7,19)	/ARBE/	Streamsheet radius.
BE	(7,19)	/ARBE/	Streamsheet thickness.
CE0		/Z/	Meridional chord of domain 1; m.
CE1		/J/	Meridional chord of domains 2 and 3; m.

<u>Name</u>	<u>Dimension</u>	<u>Common</u>	<u>Definition</u>
CE2		/J/	Meridional chord of domains 5 and 6; m.
CE7		/Z/	Meridional chord of domain 7; m.
C4		/J/	Meridional chord of domain 4; m.
DSL	(2,19,3)	/Q/	Displacement thickness on upper surface of lower blade.
DSLM	(2,9,4)	/UQ/	Displacement thickness on lower surface of lower blade at J=1, 2, 3, and 4. (Used when IBLEQ=1.) [*]
DSLRL	(2,9,4)	/UQ/	Displacement thickness on lower surface of lower blade at J=JS-2, JS-1, JS and JS+1. (Used when IBLEQ=1.)
DSSL	(3,19,3)	/Q/	Wake displacement thickness along slipstream of lower blade.
DSSLM	(3,9,19)	/UQ/	Displacement thickness along interior side of lower slipstream. (Used when IBLEQ=1.)
DSSU	(3,19,3)	/Q/	Wake displacement thickness along slipstream of upper blade.
DSSUM	(3,9,19)	/UQ/	Displacement thickness along interior side of upper slipstream. (Used when IBLEQ=1.)
DSU	(2,19,3)	/Q/	Displacement thickness on lower surface of upper blade.
DSUM	(2,9,4)	/UQ/	Displacement thickness on upper surface of upper blade at J = 1, 2, 3 and 4. (Used when IBLEQ=1.)
DSUR	(2,9,4)	/UQ/	Displacement thickness on upper surface of upper blade at J = JS-2, JS-1, JS and JS+1. (Used when IBLEQ=1.)
DT,DTF,DTØ2		/H/	Non-dimensional time step.
DX		/Z/	Non-dimensional meridional mesh length.
ES1		/J/	Circumferential angle between two blades of first blade row; radians.

*A number of additional variables are introduced by the time-phased boundary conditions employed for unequal numbers of blades. These are denoted by the comment "used when IBLEQ=1".

<u>Name</u>	<u>Dimension</u>	<u>Common</u>	<u>Definition</u>
ES2		/J/	Circumferential angle between two blades of second blade row; radians.
E1	(7,19,15)	/P/	Relative total internal energy at beginning of each time step.
E2	(7,19,15)	/ /	Relative total internal energy at end of each time step. May be either predictor or corrector value.
GAMMA		/Z/	Ratio of specific heats.
GAML1		/Z/	GAMMA-1.
IBCE		/C/	Inlet and discharge boundary conditions indicator (input).
IBLEQ		/C/	Equal number of blades indicator (input).
ID		/C/	Domain index.
IDEBUG		/C/	Final time step for run, equal blade stages or single stage (input).
IDELTA		/L/	Viscosity indicator (input).
IFØR		/C/	Number of blade rows indicator (input).
INEW			New stage geometry indicator (input).
IØNE		/C/	Indicator for domains 1 and 7 (input).
IREST		/EXTRA/	Internal initial start (1) and continuation (0) indicator.
ISLLE		/C/	Leading edge slope indicator (input).
ISLTE		/C/	Trailing edge slope indicator (input).
ISTART		/L/	Restart indicator (input).
ITER		/C/	MacCormack predictor/corrector iteration counter.
ITIME		/L/	Time step from beginning of case (modified internally by addition of NNN when IBLEQ=1).
J		/C/	Meridional mesh column index.
JF	(7)	/N1/	Final interior meridional mesh column of each domain.
JI	(7)	/N1/	Initial interior meridional mesh column of each domain.

<u>Name</u>	<u>Dimension</u>	<u>Common</u>	<u>Definition</u>
JS		/C/	Number of meridional mesh lines + 1 in each domain (input).
JSL			JS-2
JSM		/C/	JS-1
JSP		/C/	JS+1
K		/C/	Circumferential grid row index.
KS		/C/	Number of circumferential mesh rows + 3 in each domain (input).
KSL		/KS/	KS-2
KSM		/C/	KS-1
KSØ		/KS/	KS+1 (KSØ is at the same circumferential location as KS for the same meridional index J.)
KSP		/C/	KS+2
KSQ		/KS/	KS+3
LBLADE		/C/	Print indicator for domain virtual points (input).
MØBL		/C/	Number of blades in second row (input).
NBLADE		/C/	Number of blade passings (input).
NØBL		/C/	Number of blades in first row (input).
ØMG	(2)	/N1/	Angular velocity (input).
PHIEX	(3)	/PHX/	Angle of lower blade slipstream with respect to meridional direction at discharge station; radians.
PHIEY	(3)	/PHINEW/	Angle of upper blade slipstream with respect to meridional direction at discharge station; radians.
PHILE	(2,3)	/PL/	Angle of flow direction at leading edge of lower blade; radians.
PHILP	(2,3)	/PHINEW/	Angle of flow direction at leading edge of upper blade; radians.
PHITE	(2,3)	/PH/	Angle of slipstream at trailing edge of lower blade; radians.

<u>Name</u>	<u>Dimension</u>	<u>Common</u>	<u>Definition</u>
PHITP	(2,3)	/PHINEW/	Angle of slipstream at trailing edge of upper blade; radians.
PM	(7,9,19)	/P1/	Static pressure at virtual point $K=KS+2$. (Used when $IBLEQ=1$.)
PMM	(7,9,19)	/UQ/	Static pressure at virtual point $K=KS+1$. (Used when $IBLEQ=1$.)
PMP	(7,9,19)	/UQ/	Static pressure at virtual point $K=KS+3$. (Used when $IBLEQ=1$.)
P1	(7,19,15)	/P/	Static pressure at beginning of each time step.
P15	(2)	/Q15/	Static pressure at leading edge "A" point of domain 5. (See Figure 9b of Reference 1.)
P2	(7,19,15)	/ /	Static pressure at end of each time step. May be either predictor or corrector value.
P3	(7,9,19)	/P1/	Static pressure at virtual point $K=2$. (Used when $IBLEQ=1$.)
P3M	(7,9,19)	/UQ/	Static pressure at virtual point $K=3$. (Used when $IBLEQ=1$.)
P3P	(7,9,19)	/UQ/	Static pressure at virtual point $K=1$. (Used when $IBLEQ=1$.)
REYCR		/Z/	Critical Reynolds number.
RM	(7,9,19)	/P1/	Static density at virtual point $K=KS+2$. (Used when $IBLEQ=1$.)
RMM	(7,9,19)	/UQ/	Static density at virtual point $K=KS+1$. (Used when $IBLEQ=1$.)
RMP	(7,9,19)	/UQ/	Static density at virtual point $K=KS+3$. (Used when $IBLEQ=1$.)
RUST	(7,9,19)	/UQ/	Weight flow rate at each station; kg/sec. (Used when $IBLEQ=1$.)
R1	(7,19,15)	/P/	Static density at beginning of each time step.
R15	(2)	/Q15/	Static density at leading edge "A" point of domain 5. (See Figure 9b of Reference 1.)

<u>Name</u>	<u>Dimension</u>	<u>Common</u>	<u>Definition</u>
R2	(7,19,15)	/ /	Static density at end of each time step. May be either predictor or corrector value.
R3	(7,9,19)	/P1/	Static density at virtual point K=KS+2. (Used when IBLEQ=1.)
R3M	(7,9,19)	/UQ/	Static density at virtual point K=KS+1. (Used when IBLEQ=1.)
R3P	(7,9,19)	/UQ/	Static density at virtual point K=KS+3. (Used when IBLEQ=1.)
THM	(2)	/YTH/	Leading edge mean angle; radians. (See Figure 9b of Reference 1.)
THN	(2)	/YTH/	Trailing edge mean angle; radians. (See Figure 9a of Reference 1.)
UM	(7,9,19)	/P1/	Meridional velocity at virtual point K=2. (Used when IBLEQ=1.)
UMM	(7,9,19)	/UQ/	Meridional velocity at virtual point K=3. (Used when IBLEQ=1.)
UMP	(7,9,19)	/UQ/	Meridional velocity at virtual point K=1. (Used when IBLEQ=1.)
U1	(7,19,15)	/P/	Meridional velocity at beginning of each time step.
U15	(2)	/Q15/	Meridional velocity at leading edge "A" point of domain 5. (See Figure 9b of Reference 1.)
U2	(7,19,15)	/ /	Meridional velocity at end of each time step. May be either predictor or corrector value.
U3	(7,9,19)	/P1/	Meridional velocity at virtual point K=KS+2. (Used when IBLEQ=1.)
U3M	(7,9,19)	/UQ/	Meridional velocity at virtual point K=KS+1. (Used when IBLEQ=1.)
U3P	(7,9,19)	/UQ/	Meridional velocity at virtual point K=KS+3. (Used when IBLEQ=1.)
VSAY	(3,19)	/VSAY/	Slipstream normal velocity.
VM	(7,9,19)	/P1/	Relative circumferential velocity at virtual point K=2. (Used when IBLEQ=1.)

<u>Name</u>	<u>Dimension</u>	<u>Common</u>	<u>Definition</u>
VMM	(7,9,19)	/UQ/	Relative circumferential velocity at virtual point K=3. (Used when IBLEQ=1.)
VMP	(7,9,19)	/UQ/	Relative circumferential velocity at virtual point K=1. (Used when IBLEQ=1.)
V1	(7,19,15)	/P/	Relative circumferential velocity at beginning of each time step.
V15	(2)	/Q15/	Relative circumferential velocity at leading edge "A" point of domain 5. (See Figure 9b of Reference 1.)
V2	(7,19,15)	/ /	Relative circumferential velocity at end of each time step. May be either predictor or corrector value.
V3	(7,9,19)	/P1/	Relative circumferential velocity at virtual point K=KS+2. (Used when IBLEQ=1.)
V3M	(7,9,19)	/UQ/	Relative circumferential velocity at virtual point K=KS+1. (Used when IBLEQ=1.)
V3P	(7,9,19)	/UQ/	Relative circumferential velocity at virtual point K=KS+3. (Used when IBLEQ=1.)
X		/Z/	Transformed meridional coordinate.
XMU		/L/	Dynamic viscosity.
YL	(2,19)	/Q/	Non-dimensional coordinate of upper surface of lower blade.
YLX	(2,19)	/Q/	Non-dimensional derivative of YL with respect to X.
YSL	(3,19,3)	/VSAY/	Non-dimensional lower blade slipstream location.
YSLM	(3,9,19)	/UQ/	Non-dimensional lower blade slipstream location. (Used when IBLEQ=1.)
YSU	(3,19,3)	/VSAY/	Non-dimensional upper blade slipstream location.
YSUM	(3,9,19)	/UQ/	Non-dimensional upper blade slipstream location. (Used when IBLEQ=1.)

<u>Name</u>	<u>Dimension</u>	<u>Common</u>	<u>Definition</u>
YSXLM	(3,9,19)	/UQ/	Non-dimensional lower blade slipstream derivative. (Used when IBLEQ=1.)
YSXUM	(3,9,19)	/UQ/	Non-dimensional upper blade slipstream derivative. (Used when IBLEQ=1.)
YU	(2,19)	/Q/	Non-dimensional coordinate of lower surface of upper blade.
YUX	(2,19)	/Q/	Non-dimensional derivative of YU with respect to X.

Machine Control Considerations

The computer program is written in FØRTRAN IV for the CDC 7600 but will also run on the CDC 6600 and comparable IBM, UNIVAC and Honeywell machines with minor modifications.

Machine Requirements:

- (a) Field Length
 - (1) Compile $\sim 120,000$ octal locations.
 - (2) Load $\sim 265,000$ octal locations ($\sim 160,000$ in SCM and $105,000$ in LCM on the CDC 7600).
- (b) CP Time - Variable, depending on domains needed for problem, mesh size and number of time steps being run. (Approximately 2.23×10^{-4} sec per mesh point per time step if IBLEQ=0, and 1.27×10^{-3} sec per mesh point per time step if IBLEQ=1 are required on a CDC 7600.)
- (c) Disk or Tape Units
 - (1) TAPE5 = card input.
 - (2) TAPE6 = printed output.
 - (3) TAPE8 = contains flow field solution to be read for current program restart.
 - (4) TAPE9 = contains flow field solution to be written out at end of run, for next restart run.

(5) TAPES 1, 2, 3 and 4 = scratch disk storage used during run for unequal blade spacing (i.e., when IBLEQ=1). Also used as input/output media for restarting the program (when IBLEQ=1).

(d) Volume of Printed Output - Variable depending on length of run and print options specified.

Abnormal Terminations

Under certain conditions the program will write an error statement and terminate execution. These are listed below according to the subroutine in which they occur:

B2DATL

(1) "INPUT DATA --- C4 MUST BE GREATER THAN OR EQUAL TO (CE1/(JS-2)) OR (CE2/(JS-2)) WITH C4 = _____ CE1 = _____
CE2 = _____"

This error message is self explanatory and indicates that C4 is too small.

(2) "BLADE HAS NEGATIVE THICKNESS"

Error in the blade contour data. Input data for the blades, YU and YL, may have been interchanged.

(3) "BLADE IS TOO THICK"

Erroneous blade data. Lower surface of upper blade overlaps the upper surface of lower blade.

(4) "MARK = 3 OR 7 OR 11 OR 12
SOMETHING IS WRONG WITH INTERPOLATION"

(a) MARK = 3

Interpolation error for locating virtual points for domain 3 within domain 4 (if domain 4 is activated), i.e., in the evaluation of JLE (the J value in domain 4 such that (3,JS+1,K) falls between (4,JLE,K) and (4,JLE+1,K)). This error message is preceded by (1) above.

(b) MARK = 7

Interpolation error for locating virtual points for domain 5, within domain 4 (if domain 4 is activated), i.e., in the evaluation of JRE (the J value in domain 4 such that (5,1,K) falls between (4,JRE,K) and (4,JRE+1,K)). This error message is preceded by (1) above.

(c) MARK = 11

Interpolation error for locating virtual points for domain 2 within domain 1 (if domain is activated), i.e., in the evaluation of JØE (the J value in domain 1 such that (2,1,K) falls between (1,JØE,K) and (1,JØE+1,K)). Domain 1 could be too short.

(d) MARK = 12

Interpolation error for locating virtual points for domain 6 within domain 7 (if domain 7 is activated), i.e., in the evaluation of J7E (the J value in domain 7 such that (6,JS+1,K) falls between (7,J7E,K) and (7,J7E+1,K)). Domain 7 could be too short.

Subroutine VEB4

(1) "MARK = 1

SOMETHING IS WRONG WITH INTERPOLATION"

Interpolation error for locating domain 4 outflow boundary (4,JS,K) by interpolation from sets of adjacent blade spacing data in domain 5 i.e., (5,2,K). If the slipstreams move beyond the range of data available, the program will stop and the above message will be printed. Also if the ratio of number of blades in the two respective blade rows exceed 3/2 this condition will occur.

Subroutine VEB5

(1) "MARK = 2

SOMETHING IS WRONG WITH INTERPOLATION"

Interpolation error for locating domain 5 virtual inflow boundary, (5,1,K) by interpolation from three sets of adjacent slipstream spacing data in domain 4 between (4,JRE,K) and (4,JRE+1,K). If the slipstream

moves beyond the physical location required by domain 5 for interpolated data the program will stop and the above message will be printed. If the ratio of the two respective blade rows is less than 1 (i.e., number of blades in first row is greater than the number of blades in second row) this condition will occur.

Subroutine TRED

- (1) "MORE THAN 10 ITERATIONS ON DATA IN TRED
 DETA, DETA1, DETA2, DXS1, DXS11, DXS12, DXSA, DXSA1, DXSA2
 _ _ _ _ _"
 Iteration limit for origin of stream path and compatibility characteristic location has been exceeded. Mesh is probably too coarse; use more mesh points, if possible.

- (2) "MORE THAN 30 ITERATIONS ON PHI ITIME, ID, ICT, PHI, 1, 2 - DP, 1, 2
 = _ _ _ _ _"
 Pressure balance vs. flow angle iteration limit has been exceeded. Try a change in blade shape at leading (ILT = 1) or trailing (ILT = 2) edge, or in the value of CØEFTH or CØEFTE.

- (3) "LOCAL MINIMUM IN TRED ITERATION"
 Pressure balance vs. flow angle iteration has found a local minimum and cannot converge within the allowable tolerance. Try corrective measures of (2).

Subroutine SURF

- (1) "MORE THAN 10 ITERATIONS ON DETA IN SURF, ETC."
 See (1) for subroutine TRED.

Subroutine SLIP

- (1) "MORE THAN 10 ITERATIONS ON DETA IN SLIP, ETC."
 See (1) for subroutine TRED.

Subroutine ONESID

(1) "MORE THAN 10 ITERATIONS ON DETA IN ONESID, ETC."

See (1) for subroutine TRED.

Subroutine WAKE

(1) "WAKE INTERPOLATION ERROR. IDM2, ID, IDQ, SSB, SL, SR = _ _ _ _ _"

Interpolation for wake evaluation failed. Data not available beyond
the end of the last domain.

APPENDIX A

SAMPLE OUTPUT FROM PROGRAM B2DATL

The following is a sampling of printed output from the rotor tip section of the 1500 fps tip speed transonic fan stage discussed in the results section of Volume 1 (Reference 1). The rotor has been run to 100 time steps.

Four sections of output are presented: the full input data, the complete section of initial data and constants derived from the input data, some intermediate output after 100 steps, and a portion of the domain output, after 100 steps. Note that the full domain output includes results from each grid column (J) of each solution domain (ID). This single blade row case had three domains (2,3, and 6) with $JS+1 = 19$ grid columns in each.

ROTOR TIP (GE-1500)

ISTART 0	ITAPE0 0	IFOB 1	ICNE 1	ISCE 1	IDIM 2	NONDIM 0	IDEBUG 100	ITBUG 0	INEW 1			
IDELTA 0	NBLADE 0	LBLADE 0	IBLEG 0	IPI 2	IKF 2	ICOR 0						
IPXT 10	IPPT 10	IPC1 10	IPHT 10	IPRT 100	JPRT 100							
IDA 0	JA 0	KA 0	IEB 0	JB 0	KB 0	IDC 0	JC 0	KC 0				
IDD 0	JD 0	KD 0	IE 0	JE 0	KE 0	ID6 0	J6 0	K6 0				
IDC1 2	JC1 2	IDC2 6	JC2 18	IDC3 0	JC3 0	IDC4 0	JC4 0	IDC5 0	JC5 0	IDC6 0	JC6 0	
IDR1 2	KR1 4	IDR2 3	KR2 4	IDR3 6	KR3 4	IDR4 3	KR4 12	IDR5 0	KR5 0	IDR6 0	KR6 0	
JS 18	KS 12	ISILE 0	ISLTE 0	NOBL 44	MCBL 44							

IDP ARRAY
0

1	1	0	0	1	0
CE1 (FT) 0.1414000E 00	YUXLE(1) (RADIANS/FT) 0.1157784E 01	YLXLE(1) (RADIANS/FT) 0.1504415E 01	YUXTE(1) (RADIANS/FT) 0.1215130E 01	YLXTE(1) (RADIANS/FT) 0.9065199E 00	
CE2 (FT) 0.1414000E 00	YUXLE(2) (RADIANS/FT) 0.0000000	YLXLE(2) (RADIANS/FT) 0.0000000	YUXTE(2) (RADIANS/FT) 0.0000000	YLXTE(2) (RADIANS/FT) 0.0000000	
C4 (FT) 0.1414000E 00					
CE3 (FT) 0.1414000E 00	CE7 (FT) 0.1414000E 00				

INPUT DATA FOR SET 1 CP 1 SETS OF BLADES

NSPU(1) NSPL(1)
13 13

STREAMSHEET COORDINATE - X (FT) (ZERO REFERENCE AT LEADING EDGE)

0.0000000	0.7805999E-02	0.1520300E-01	0.2996600E-01	0.4465400E-01	0.5923300E-01	0.7007295E-01	0.8436197E-01
0.9837699E-01	0.1121200E 00	0.1256340E 00	0.1322800E 00	0.1414000E 00			

BLADE COORDINATES - Y (RADIANS)

0.0000000	0.9099998E-02	0.1829400E-01	0.3681500E-01	0.5548000E-01	0.7433599E-01	0.8862698E-01	0.1078640E 00
0.1263390E 00	0.1430939E 00	0.1587940E 00	0.1668000E 00	0.1785250E 00			

STREAMSHEET COORDINATE - X (FT) (ZERO REFERENCE AT LEADING EDGE)

C.000000	0.5565997E-02	0.1234400E-01	0.2593300E-01	0.3959600E-01	0.5336800E-01	0.6379098E-01	0.7785296E-01
0.9218997E-01	0.1067970E 00	0.1216339E 00	0.1291640E 00	0.1414000E 00			

BLADE COORDINATES - Y (RADIANS)

0.000000	0.8913998E-02	0.1900000E-01	0.3813700E-01	0.5712400E-01	0.7622194E-01	0.9062999E-01	0.1099380E 00
0.1284920E 00	0.1451700E 00	0.1604249E 00	0.1673999E 00	0.1785250E 00			

NS(1)	NS(2)
25	25

STREAMSHEET COORDINATE - X (FT) (ZERO REFERENCE AT DOMAIN 2, J=2)

-0.1500000E 00	-0.1414000E 00	-0.9809995E-01	0.0000000	0.4890000E-01	0.8937997E-01	0.1414000E 00	0.1977299E 00
0.2420000E 00	0.2820000E 00	0.2970000E 00	0.3803000E 00	0.4242000E 00	0.4928400E 00	0.5670200E 00	0.6873000E 00
0.7886699E 00	0.7977099E 00	0.8393800E 00	0.9227000E 00	0.1084499E 01	0.1179999E 01	0.1280000E 01	0.1380329E 01
0.1400000E 01							

STREAMSHEET RADIUS - AR (FT)

C.1527200E 01	0.1527100E 01	0.1526899E 01	0.1526600E 01	0.1524099E 01	0.1520829E 01	0.1514290E 01	0.1504299E 01
0.1495500E 01	0.1490999E 01	0.1489599E 01	0.1486699E 01	0.1486500E 01	0.1486400E 01	0.1486340E 01	0.1486309E 01
0.1486300E 01	0.1486300E 01	0.1486300E 01	0.1486300E 01	0.1486300E 01	0.1486300E 01	0.1486300E 01	0.1486300E 01
0.1486300E 01							

STREAMSHEET COORDINATE - X (FT) (ZERO REFERENCE AT DOMAIN 2, J=2)

-0.1500000E 00	-0.1414000E 00	-0.9809995E-01	0.0000000	0.4890000E-01	0.8937997E-01	0.1414000E 00	0.1977299E 00
0.2420000E 00	0.2820000E 00	0.2970000E 00	0.3803000E 00	0.4242000E 00	0.4928400E 00	0.5670200E 00	0.6873000E 00
0.7886699E 00	0.7977099E 00	0.8393800E 00	0.9227000E 00	0.1084499E 01	0.1179999E 01	0.1280000E 01	0.1380329E 01
0.1400000E 01							

STREAMSHEET THICKNESS - BE (FT)

0.5843000E-02	0.5840000E-02	0.5836997E-02	0.5833998E-02	0.5824998E-02	0.5749997E-02	0.5557999E-02	0.5124997E-02
0.4816998E-02	0.4717000E-02	0.4719999E-02	0.4874997E-02	0.4949998E-02	0.4949998E-02	0.4949998E-02	0.4949998E-02
0.4949998E-02	0.4949998E-02	0.4949998E-02	0.4949998E-02	0.4949998E-02	0.4949998E-02	0.4949998E-02	0.4949998E-02
0.4949998E-02							

OMG(1)	OMG(2)	PI	TI	UI	VOUI	DELS55
(RADIANS/SEC)	(RADIANS/SEC)	(LBF/(FT**2))	(DEG R)	(FT/SEC)		
-0.9747378E 03	-0.9747378E 03	0.1684800E 04	0.4870000E 03	0.6170000E 03	0.0000000	0.0000000

DAMPC	DAMPC1	DAMPI	DAMPI1
0.1000000E-04	0.1000000E 01	0.3000000E 03	0.6000000E 03

PPF	AFF	UPF
(LBF/(FT**2))	(FT/SEC)	(FT/SEC)
0.2435640E 04	0.1165180E 04	0.6010000E 03

R	GAMMA	REYCR	XMU	COEPTH	COEPTC
FT*LBF/SLG/DEGR			(LBF*SEC/FT**2)		
0.1716000E 04	0.1400000E 01	0.6000000E 06	0.3750000E-06	0.1000000E 01	0.6666666E 00

UZ	CDT
0.1000000E 01	0.2500000E 01

PC	TC	UC	VOUC
(LBF/(FT**2))	(DEG R)	(FT/SEC)	
0.1684800E 04	0.4870000E 03	0.6170000E 03	0.0000000

INITIALIZED INPUT DATA AND GENERAL CONSTANTS

JI ARRAY

3	3	2	3	2	3	3
---	---	---	---	---	---	---

JF ARRAY

17	17	18	17	18	17	17
----	----	----	----	----	----	----

ES1 (RADIAN)	ES2 (RADIAN)
0.1427996E 00	0.1427996E 00

TIME
0.0000000

PI (REF)	AI (REF)	TA (REF)	XHUB (REF)
(LBF/(FT**2))	(FT/SEC)	(DEG R)	(LBF*SEC/FT**2)
0.1684800E 04	0.1081651E 04	0.6817998E 03	0.2202473E 00

ITIMEF = 100

DX	DN	DT
0.62500E-01	0.12500E 00	0.19885E-01

FIRST ELADE

J	YU	YL	YUX	YIX
1	0.91655E 00	-0.53442E-01	0.13351E 01	0.13351E 01
2	0.10000E 01	0.00000	0.11139E 01	0.16277E 01
3	0.10725E 01	0.97135E-01	0.12117E 01	0.14711E 01
4	0.11490E 01	0.18625E 00	0.12420E 01	0.13964E 01
5	0.12274E 01	0.27271E 00	0.12427E 01	0.13765E 01
6	0.13055E 01	0.35872E 00	0.12554E 01	0.13758E 01
7	0.13543E 01	0.44467E 00	0.12646E 01	0.13742E 01
8	0.14040E 01	0.53044E 00	0.12822E 01	0.13702E 01
9	0.15447E 01	0.61590E 00	0.12941E 01	0.13687E 01
10	0.16265E 01	0.70150E 00	0.13229E 01	0.13631E 01
11	0.17094E 01	0.78575E 00	0.13372E 01	0.13275E 01
12	0.17931E 01	0.86661E 00	0.13228E 01	0.12527E 01
13	0.18743E 01	0.94159E 00	0.12703E 01	0.11481E 01
14	0.19514E 01	0.10109E 01	0.11997E 01	0.10772E 01
15	0.20247E 01	0.10765E 01	0.11495E 01	0.10163E 01
16	0.20563E 01	0.11373E 01	0.11554E 01	0.92581E 00
17	0.21705E 01	0.11939E 01	0.12301E 01	0.90085E 00
18	0.22502E 01	0.12502E 01	0.13101E 01	0.89912E 00
19	0.23175E 01	0.13175E 01	0.10767E 01	0.10767E 01

DOMAIN 2

J	AR	BE	ARX	BEX
2	0.10796E 02	0.41259E-01	-0.30705E-01	0.15753E-03
3	0.10794E 02	0.41269E-01	-0.39279E-01	0.16358E-03
4	0.10791E 02	0.41277E-01	-0.46968E-01	0.73285E-04

5	0.10788E 02	0.41276E-01	-0.53773E-01	-0.11334E-03
6	0.10785E 02	0.41261E-01	-0.59693E-01	-0.39629E-03
7	0.10781E 02	0.41225E-01	-0.64730E-01	-0.77557E-03
8	0.10777E 02	0.41162E-01	-0.69111E-01	-0.12326E-02
9	0.10772E 02	0.41072E-01	-0.74420E-01	-0.16372E-02
10	0.10767E 02	0.40959E-01	-0.80955E-01	-0.19712E-02
11	0.10762E 02	0.40827E-01	-0.86716E-01	-0.22156E-02
12	0.10756E 02	0.40682E-01	-0.92704E-01	-0.24113E-02
13	0.10750E 02	0.40526E-01	-0.10732E 00	-0.26073E-02
14	0.10743E 02	0.40353E-01	-0.11663E 00	-0.29507E-02
15	0.10735E 02	0.40154E-01	-0.12565E 00	-0.34432E-02
16	0.10727E 02	0.39919E-01	-0.13435E 00	-0.40847E-02
17	0.10718E 02	0.39640E-01	-0.14275E 00	-0.48753E-02
18	0.10709E 02	0.39307E-01	-0.15085E 00	-0.58148E-02

DOMAIN 3

J	AR	BE	ARX	BEX
1	0.10718E 02	0.39640E-01	-0.14275E 00	-0.48753E-02
2	0.10709E 02	0.39307E-01	-0.15085E 00	-0.58148E-02
3	0.10700E 02	0.38914E-01	-0.15888E 00	-0.67264E-02
4	0.10689E 02	0.38470E-01	-0.16709E 00	-0.74413E-02
5	0.10679E 02	0.37968E-01	-0.17547E 00	-0.79533E-02
6	0.10667E 02	0.37440E-01	-0.18403E 00	-0.82646E-02
7	0.10656E 02	0.36959E-01	-0.19277E 00	-0.83750E-02
8	0.10643E 02	0.36437E-01	-0.20169E 00	-0.82847E-02
9	0.10630E 02	0.35927E-01	-0.20926E 00	-0.80018E-02
10	0.10617E 02	0.35440E-01	-0.20977E 00	-0.75573E-02
11	0.10604E 02	0.34936E-01	-0.20267E 00	-0.69542E-02
12	0.10592E 02	0.34574E-01	-0.19798E 00	-0.61925E-02
13	0.10581E 02	0.34215E-01	-0.16568E 00	-0.52721E-02
14	0.10572E 02	0.33918E-01	-0.13793E 00	-0.42212E-02
15	0.10564E 02	0.33687E-01	-0.11642E 00	-0.31920E-02
16	0.10557E 02	0.33519E-01	-0.10291E 00	-0.22072E-02
17	0.10551E 02	0.33410E-01	-0.97384E-01	-0.12670E-02
18	0.10545E 02	0.33359E-01	-0.99851E-01	-0.37121E-03
19	0.10538E 02	0.33360E-01	-0.98816E-01	0.36358E-03

DOMAIN 6

J	AR	BE	ARX	BEX
2	0.10545E 02	0.33359E-01	-0.99851E-01	-0.37121E-03
3	0.10538E 02	0.33360E-01	-0.98816E-01	0.36358E-03
4	0.10532E 02	0.33399E-01	-0.84036E-01	0.83805E-03
5	0.10528E 02	0.33464E-01	-0.68084E-01	0.12157E-02
6	0.10524E 02	0.33507E-01	-0.53909E-01	0.15374E-02
7	0.10521E 02	0.33655E-01	-0.41559E-01	0.18031E-02
8	0.10519E 02	0.33774E-01	-0.31036E-01	0.20128E-02
9	0.10517E 02	0.33925E-01	-0.22337E-01	0.21665E-02
10	0.10516E 02	0.34044E-01	-0.15465E-01	0.22642E-02
11	0.10515E 02	0.34137E-01	-0.10417E-01	0.23059E-02
12	0.10515E 02	0.34331E-01	-0.71981E-02	0.22915E-02
13	0.10514E 02	0.34472E-01	-0.58012E-02	0.22212E-02
14	0.10514E 02	0.34607E-01	-0.53571E-02	0.20914E-02
15	0.10513E 02	0.34732E-01	-0.48636E-02	0.18982E-02
16	0.10513E 02	0.34843E-01	-0.43218E-02	0.16416E-02
17	0.10513E 02	0.34936E-01	-0.37317E-02	0.13216E-02
18	0.10513E 02	0.35007E-01	-0.30933E-02	0.93816E-03

ITIME	PHILE(1,1)	PHITE(1,1)	PHILE(1,2)	PHITE(1,2)	PHILE(1,3)	PHITE(1,3)
100	1.17760E 00	1.09946E 00	1.17759E 00	1.09997E 00	1.177C9E 00	1.1C147E 00

ITIME	PHILP(1,1)	PHITP(1,1)	PHILP(1,2)	PHITP(1,2)	PHILP(1,3)	PHITP(1,3)
100	1.17760E 00	1.09946E 00	1.17759E 00	1.09997E 00	1.17709E 00	1.10147E 00

J	YSL(2,J,3)	YSXL(2,J,3)	VSAY(2,J)	YSU(2,J,3)	YSXU(2,J,3)	VSAYP(2,J)
2	2.661802E-01	1.971933E 00	0.000000	4.790941E-01	1.971933E 00	0.000000
3	2.803409E-01	1.620323E 00	9.911882E-07	4.931278E-01	1.620323E 00	9.911882E-07
4	2.944992E-01	1.619435E 00	1.009410E-06	5.071695E-01	1.619435E 00	1.009410E-06
5	3.086715E-01	1.618706E 00	1.028392E-06	5.212460E-01	1.618706E 00	1.028392E-06
6	3.228603E-01	1.618121E 00	9.712594E-07	5.353580E-01	1.618121E 00	9.712594E-07
7	3.370652E-01	1.617604E 00	8.580326E-07	5.495329E-01	1.617604E 00	8.580326E-07
8	3.512866E-01	1.617317E 00	8.367729E-07	5.636781E-01	1.617317E 00	8.367729E-07
9	3.655213E-01	1.617062E 00	8.632671E-07	5.778799E-01	1.617062E 00	8.632671E-07
10	3.797696E-01	1.616892E 00	9.355032E-07	5.921043E-01	1.616892E 00	9.355032E-07
11	3.940290E-01	1.616757E 00	9.804062E-07	6.063476E-01	1.616757E 00	9.804062E-07
12	4.082961E-01	1.616675E 00	9.899668E-07	6.206039E-01	1.616675E 00	9.899668E-07
13	4.225675E-01	1.616614E 00	9.944279E-07	6.348673E-01	1.616614E 00	9.944279E-07
14	4.368403E-01	1.616562E 00	1.045158E-06	6.491333E-01	1.616562E 00	1.045158E-06
15	4.511131E-01	1.616513E 00	1.128252E-06	6.633996E-01	1.616513E 00	1.128252E-06
16	4.653862E-01	1.616468E 00	1.206731E-06	6.776668E-01	1.616468E 00	1.206731E-06
17	4.796598E-01	1.616440E 00	1.278616E-06	6.919352E-01	1.616440E 00	1.278616E-06
18	4.939355E-01	1.616408E 00	1.306808E-06	7.062068E-01	1.616408E 00	1.306808E-06

PHIEX(1)	PHIEY(1)	PHIEX(2)	PHIEY(2)	PHIEX(3)	PHIEY(3)
1.01677E 00	1.01677E 00	1.01677E 00	1.01677E 00	1.01677E 00	1.01677E 00

ITIME= 100

		IDC1 = 2		JC1 = 2		IDC2 = 6		JC2 = 18			
K	P	R	U	V	E	P	R	U	V	E	
4	1.02414E 00	1.42406E 00	5.53351E-01	1.37570E 00	1.95101E 00	1.56749E 00	1.92999E 00	4.09145E-01	9.09733E-01	1.63073E 00	
5	1.02389E 00	1.42380E 00	5.53524E-01	1.37576E 00	1.95107E 00	1.48067E 00	1.85215E 00	4.59147E-01	8.84163E-01	1.59764E 00	
6	1.02335E 00	1.42328E 00	5.53899E-01	1.37578E 00	1.95104E 00	1.52209E 00	1.88991E 00	4.78769E-01	8.51017E-01	1.59294E 00	
7	1.02287E 00	1.42279E 00	5.54242E-01	1.37574E 00	1.95092E 00	1.55024E 00	1.91409E 00	4.93688E-01	8.56277E-01	1.61602E 00	
8	1.02272E 00	1.42265E 00	5.54340E-01	1.37565E 00	1.95079E 00	1.57699E 00	1.93700E 00	5.07582E-01	8.78220E-01	1.65258E 00	
9	1.02300E 00	1.42293E 00	5.54146E-01	1.37559E 00	1.95073E 00	1.59712E 00	1.95447E 00	5.17496E-01	9.21751E-01	1.70441E 00	
10	1.02356E 00	1.42348E 00	5.53756E-01	1.37557E 00	1.95077E 00	1.60145E 00	1.95889E 00	5.18686E-01	9.72657E-01	1.75415E 00	
11	1.02397E 00	1.42389E 00	5.53471E-01	1.37562E 00	1.95089E 00	1.59101E 00	1.94729E 00	5.17080E-01	1.03387E 00	1.81351E 00	
12	1.02414E 00	1.42406E 00	5.53351E-01	1.37570E 00	1.95101E 00	1.56749E 00	1.92999E 00	5.22819E-01	1.09348E 00	1.86773E 00	

ITIME= 100

J	P	R	U	V	E
2	1.02414E 00	1.42406E 00	5.53351E-01	1.37570E 00	1.95101E 00
3	1.03094E 00	1.43082E 00	5.48575E-01	1.37546E 00	1.95183E 00
4	1.04192E 00	1.44166E 00	5.40922E-01	1.37500E 00	1.95300E 00
5	1.05585E 00	1.45536E 00	5.31432E-01	1.37470E 00	1.95494E 00
6	1.07060E 00	1.46994E 00	5.21540E-01	1.37478E 00	1.95761E 00
7	1.08071E 00	1.47972E 00	5.15116E-01	1.37445E 00	1.95952E 00
8	1.09064E 00	1.47981E 00	5.15892E-01	1.37527E 00	1.96155E 00
9	1.06930E 00	1.46900E 00	5.24426E-01	1.37506E 00	1.96150E 00
10	1.05439E 00	1.45407E 00	5.36798E-01	1.37307E 00	1.95936E 00
11	1.04393E 00	1.44332E 00	5.46259E-01	1.36946E 00	1.95484E 00
12	1.04346E 00	1.44368E 00	5.48591E-01	1.36769E 00	1.95344E 00
13	1.04679E 00	1.44589E 00	5.46692E-01	1.36213E 00	1.94893E 00
14	1.03600E 00	1.43609E 00	5.53589E-01	1.36879E 00	1.95661E 00
15	1.07020E 00	1.39947E 00	5.76953E-01	1.37751E 00	1.96634E 00
16	9.50503E-01	1.35094E 00	6.13127E-01	1.39761E 00	1.98936E 00
17	9.62786E-01	1.36156E 00	6.17352E-01	1.37244E 00	1.96747E 00
18	1.05156E 00	1.45028E 00	5.58360E-01	1.34417E 00	1.94087E 00

P	R	U	V	E
1.07534E 00	1.47364E 00	5.38396E-01	1.34020E 00	1.93622E 00
1.00179E 00	1.40119E 00	6.00337E-01	1.34937E 00	1.94860E 00
9.54294E-01	1.35361E 00	6.37031E-01	1.35786E 00	1.95467E 00
9.40563E-01	1.33970E 00	6.48177E-01	1.36056E 00	1.96503E 00
9.40824E-01	1.33986E 00	6.49099E-01	1.36040E 00	1.96763E 00
9.43424E-01	1.34235E 00	6.49641E-01	1.35837E 00	1.96884E 00
9.49642E-01	1.34856E 00	6.50131E-01	1.35345E 00	1.96874E 00
9.63541E-01	1.36261E 00	6.49020E-01	1.34632E 00	1.96662E 00
9.82063E-01	1.38133E 00	6.45691E-01	1.33445E 00	1.96105E 00
9.90843E-01	1.39024E 00	6.55757E-01	1.31828E 00	1.95278E 00
9.81803E-01	1.38127E 00	6.85572E-01	1.29900E 00	1.94485E 00
9.52805E-01	1.35208E 00	7.37098E-01	1.27871E 00	1.94201E 00
9.45876E-01	1.34512E 00	7.72814E-01	1.25677E 00	1.93903E 00
9.37835E-01	1.33701E 00	8.08439E-01	1.23937E 00	1.94247E 00
8.85077E-01	1.28290E 00	8.78979E-01	1.22677E 00	1.95877E 00
9.34597E-01	1.33384E 00	8.81309E-01	1.19615E 00	1.95174E 00
1.51415E 00	1.88279E 00	7.19528E-01	9.89353E-01	1.85611E 00

J	P	R	U	V	E
2	1.51415E 00	1.88279E 00	5.53293E-01	1.09106E 00	1.85611E 00
3	1.55628E 00	1.92019E 00	5.48275E-01	1.07711E 00	1.85499E 00
4	1.55544E 00	1.91955E 00	5.45617E-01	1.07571E 00	1.85262E 00
5	1.56283E 00	1.92610E 00	5.38572E-01	1.06746E 00	1.84347E 00
6	1.55623E 00	1.92028E 00	5.39529E-01	1.05777E 00	1.83190E 00
7	1.53503E 00	1.90152E 00	5.44530E-01	1.05052E 00	1.82176E 00
8	1.52905E 00	1.89419E 00	5.46344E-01	1.04269E 00	1.81055E 00
9	1.52011E 00	1.89531E 00	5.38026E-01	1.03415E 00	1.79716E 00
10	1.53503E 00	1.90189E 00	5.20852E-01	1.02001E 00	1.77659E 00
11	1.54217E 00	1.90769E 00	5.01838E-01	9.97728E-01	1.74702E 00
12	1.54548E 00	1.91600E 00	4.62958E-01	9.68975E-01	1.71080E 00
13	1.54530E 00	1.91044E 00	4.65190E-01	9.41064E-01	1.67572E 00
14	1.54652E 00	1.91151E 00	4.46387E-01	9.20282E-01	1.64833E 00
15	1.54646E 00	1.91146E 00	4.30506E-01	9.10379E-01	1.63234E 00
16	1.54746E 00	1.91233E 00	4.19865E-01	9.08105E-01	1.62617E 00
17	1.55240E 00	1.91670E 00	4.12524E-01	9.09854E-01	1.62659E 00
18	1.56749E 00	1.92999E 00	4.09145E-01	9.09733E-01	1.63073E 00

P	R	U	V	E
1.37730E 00	1.75859E 00	6.60160E-01	1.12957E 00	1.84275E 00
1.37935E 00	1.76079E 00	6.18341E-01	1.14473E 00	1.87541E 00
1.36606E 00	1.76717E 00	6.04610E-01	1.14623E 00	1.87292E 00
1.37401E 00	1.75622E 00	6.06503E-01	1.14929E 00	1.87450E 00
1.34749E 00	1.73178E 00	6.05832E-01	1.15556E 00	1.87605E 00
1.25607E 00	1.64685E 00	6.18534E-01	1.19399E 00	1.38903E 00
1.15387E 00	1.55564E 00	6.33453E-01	1.23456E 00	1.90694E 00
1.04324E 00	1.44222E 00	6.52538E-01	1.28595E 00	1.93056E 00
9.42732E-01	1.34162E 00	6.63619E-01	1.33103E 00	1.94756E 00
9.31444E-01	1.33026E 00	6.56772E-01	1.32986E 00	1.93758E 00
1.14456E 00	1.54124E 00	6.11696E-01	1.22391E 00	1.88178E 00
1.52259E 00	1.88989E 00	5.50053E-01	1.05574E 00	1.81377E 00
1.70883E 00	2.05242E 00	5.36050E-01	9.70805E-01	1.78910E 00
1.66563E 00	2.01536E 00	5.88608E-01	9.85941E-01	1.80792E 00
1.54951E 00	1.91411E 00	6.00503E-01	1.04598E 00	1.84637E 00
1.46944E 00	1.86092E 00	5.93143E-01	1.09927E 00	1.87734E 00
1.51415E 00	1.88301E 00	5.55600E-01	1.11316E 00	1.88153E 00

ITIME = 100 TIME = 1.988442 00 ID = 2 J = 17 X = 1.32562E-01 (FEET) MDOT = 1.55163E-03 (SLG/SEC)

K	Y (RADIAN)	P	RHO	U	V	E	T	H	M	S
4	-2.65293E-01	9.62786E-01	1.36156E 00	6.17153E-01	1.37244E 00	1.96747E 00	7.07111E-01	2.67459E 00	1.51250E 00	1.04839E-03
5	-2.47443E-01	1.02001E 00	1.42000E 00	5.80050E-01	1.35099E 00	1.94344E 00	7.18317E-01	2.66225E 00	1.46612E 00	4.65065E-05
6	-2.29593E-01	1.05314E 00	1.45360E 00	5.58752E-01	1.33943E 00	1.93172E 00	7.24505E-01	2.65823E 00	1.44103E 00	8.23267E-04
7	-2.11743E-01	1.05353E 00	1.45306E 00	5.53540E-01	1.34052E 00	1.93226E 00	7.25046E-01	2.65731E 00	1.43993E 00	7.19242E-05
8	-1.93893E-01	1.01993E 00	1.41891E 00	5.72913E-01	1.35546E 00	1.94691E 00	7.18738E-01	2.66565E 00	1.46700E 00	6.46259E-04
9	-1.76043E-01	9.90844E-01	1.39023E 00	5.91324E-01	1.36810E 00	1.95972E 00	7.12689E-01	2.67241E 00	1.49209E 00	5.43885E-04
10	-1.58193E-01	9.52496E-01	1.35231E 00	6.11675E-01	1.38158E 00	1.96965E 00	7.04343E-01	2.67400E 00	1.52156E 00	1.49161E-04
11	-1.40343E-01	9.10580E-01	1.30785E 00	6.31437E-01	1.39840E 00	1.98504E 00	6.96240E-01	2.68128E 00	1.55411E 00	1.68439E-03
12	-1.22493E-01	9.62786E-01	1.36156E 00	6.17353E-01	1.37244E 00	1.96747E 00	7.07111E-01	2.67459E 00	1.51250E 00	1.04839E-03

K	Y (F=FEET)	P (LBF/F**2)	R (SLG/F**3)	U (F/SEC)	V (F/SEC)	Q (F/SEC)	BETA (DEG)	T (DEG - P)	PT (LBF/F**2)	STREAM FNCT
4	-4.02374E-01	1.62210E 03	1.96071E-03	6.67760E 02	1.48450E 03	1.62777E 03	6.57806E 01	4.82111E 02	2.10301E 03	1.10703E-02
5	-3.75021E-01	1.71851E 03	2.04466E-03	6.27412E 02	1.46130E 03	1.59030E 03	6.67636E 01	4.83744E 02	2.15609E 03	1.37737E-01
6	-3.47968E-01	1.77433E 03	2.09324E-03	6.04375E 02	1.44479E 03	1.56980E 03	6.73562E 01	4.93967E 02	2.18794E 03	2.62244E-01
7	-3.20915E-01	1.77499E 03	2.09246E-03	5.99169E 02	1.45030E 03	1.56919E 03	6.75527E 01	4.94336E 02	2.18072E 03	3.85323E-01
8	-2.93861E-01	1.71820E 03	2.04329E-03	6.19691E 02	1.46613E 03	1.59171E 03	6.70876E 01	4.90035E 02	2.14373E 03	5.08457E-01
9	-2.66806E-01	1.66937E 03	2.00207E-03	6.39606E 02	1.47980E 03	1.61211E 03	6.66248E 01	4.85910E 02	2.11604E 03	6.32899E-01
10	-2.39755E-01	1.60477E 03	1.94738E-03	6.61619E 02	1.49439E 03	1.63430E 03	6.61193E 01	4.80224E 02	2.07330E 03	7.58428E-01
11	-2.12702E-01	1.53414E 03	1.88336E-03	6.82994E 02	1.51258E 03	1.65963E 03	6.56989E 01	4.74696E 02	2.02162E 03	8.84239E-01
12	-1.85649E-01	1.62210E 03	1.96071E-03	6.67760E 02	1.48450E 03	1.62777E 03	6.57806E 01	4.82111E 02	2.10301E 03	1.01107E 00

ITIME = 100 TIME = 1.98844E 00 ID = 2 J = 18 X = 1.41400E-01 (FEET) MDOT = 1.55457E-03 (SLG/SEC)

K	Y (RADIAN)	P	RHO	U	V	E	T	H	M	S
4	-2.53377E-01	1.05156E 00	1.45028E 00	5.58360E-01	1.34417E 00	1.94087E 00	7.25070E-01	2.66594E 00	1.44466E 00	8.70243E-04
5	-2.35527E-01	1.06676E 00	1.46432E 00	5.52030E-01	1.33679E 00	1.93603E 00	7.28493E-01	2.66453E 00	1.43211E 00	1.73157E-03
6	-2.17677E-01	1.03999E 00	1.43601E 00	5.66277E-01	1.34581E 00	1.94289E 00	7.23214E-01	2.66611E 00	1.45106E 00	1.70554E-03
7	-1.99827E-01	9.95190E-01	1.39421E 00	5.91947E-01	1.36289E 00	1.95738E 00	7.13802E-01	2.67119E 00	1.48641E 00	9.79565E-04
8	-1.81978E-01	9.48995E-01	1.34837E 00	6.23673E-01	1.37932E 00	1.97419E 00	7.03810E-01	2.67800E 00	1.52499E 00	2.54493E-04
9	-1.64128E-01	9.33756E-01	1.33345E 00	6.29450E-01	1.38703E 00	1.97959E 00	7.00258E-01	2.67985E 00	1.53835E 00	3.52681E-04
10	-1.46278E-01	9.00937E-01	1.29871E 00	6.47068E-01	1.39922E 00	1.99146E 00	6.93716E-01	2.68518E 00	1.56428E 00	8.17597E-04
11	-1.28428E-01	9.65731E-01	1.36630E 00	6.32988E-01	1.36846E 00	1.97265E 00	7.06821E-01	2.67947E 00	1.51571E 00	7.61084E-04
12	-1.10578E-01	1.05156E 00	1.45028E 00	5.58360E-01	1.34417E 00	1.94087E 00	7.25070E-01	2.66594E 00	1.44466E 00	8.70243E-04

K	Y (F=FEET)	P (LBF/F**2)	R (SLG/F**3)	U (F/SEC)	V (F/SEC)	Q (F/SEC)	BETA (DEG)	T (DEG - R)	PT (LBF/F**2)	STREAM FNCT
4	-3.83687E-01	1.77166E 03	2.08847E-03	6.03950E 02	1.45392E 03	1.57437E 03	6.74422E 01	4.94352E 02	2.18329E 03	0.00000
5	-3.56657E-01	1.79727E 03	2.10869E-03	5.97103E 02	1.44594E 03	1.56438E 03	6.75617E 01	4.96689E 02	2.20321E 03	1.21797E-01
6	-3.29627E-01	1.75218E 03	2.07073E-03	6.12514E 02	1.45570E 03	1.57931E 03	6.71801E 01	4.93087E 02	2.17286E 03	2.43914E-01
7	-3.02597E-01	1.67670E 03	2.00772E-03	6.40334E 02	1.47417E 03	1.60723E 03	6.65212E 01	4.86650E 02	2.12567E 03	3.67323E-01
8	-2.75567E-01	1.59887E 03	1.94170E-03	6.74596E 02	1.49194E 03	1.63737E 03	6.56694E 01	4.79857E 02	2.08632E 03	4.92736E-01
9	-2.48537E-01	1.57319E 03	1.92021E-03	6.80845E 02	1.50028E 03	1.64754E 03	6.55909E 01	4.77436E 02	2.06573E 03	6.19200E-01
10	-2.21507E-01	1.51790E 03	1.87020E-03	6.99902E 02	1.51347E 03	1.66747E 03	6.51818E 01	4.72975E 02	2.02910E 03	7.45620E-01
11	-1.94477E-01	1.62766E 03	1.96753E-03	6.84672E 02	1.48020E 03	1.63088E 03	6.51769E 01	4.81910E 02	2.13683E 03	6.73960E-01
12	-1.67447E-01	1.77166E 03	2.08847E-03	6.03950E 02	1.45392E 03	1.57437E 03	6.74422E 01	4.94352E 02	2.18329E 03	9.99999E-01

APPENDIX B
SUBROUTINES AND COMMON BLOCKS WHICH MUST BE
CHANGED TO INCREASE THE MAXIMUM VALUES OF JS+1 AND KS+3

In order to alter the program dimension for the maximum allowable meridional (J) or circumferential (K) subscript value, the following common blocks in the indicated routines must be changed from the current values (JS+1=19 and KS+3=15 respectively) to the desired value.

<u>Common Block</u>	<u>Variables</u>	<u>Subroutines</u>
/ /	R2, P2, U2, V2, E2	B2DATL, UNCØM2, ITER1, UNEQ, TRED, SLIP, HØBA, VEB1, VEB4, VEB5, CHAR1, CHARØ, SURF, WAKE, EXTRA2, ØNESID
/P/	R1, P1, U1, V1, E1	B2DATL, UNCØM2, ITER1, UNEQ, TRED, SLIP, HØBA, VEB1, VEB4, VEB5, CHAR1, CHARØ, SURF, WAKE, EXTRA2, ØNESID
/Q/	DSU, DS2, YU, Y2, YUX, YLX, YUXX, YLXX, DSSL, DSSU	B2DATL, UNCØM2, ITER1, UNEQ, TRED, SLIP, HØBA, VEB1, VEB4, VEB5, CHAR1, CHARØ, SURF, WAKE, PSØLV, QSØLV, EXTRA2, ØNESID
/ARBE/	AR, BE, ARX, BEX	B2DATL, UNCØM2, ITER1, UNEQ, TRED, SLIP, HØBA, VEB1, VEB4, VEB5, CHAR1, CHARØ, SURF, WAKE, QSØLV, PSØLV, EXTRA2, ØNESID
/VSAY/	VSAY, VSAYP, YSL YSU, YSXL, YSXU	B2DATL, UNCØM2, ITER1, UNEQ, TRED, SLIP, HØBA, VEB1, VEB4, VEB5, CHAR1, CHARØ, SURF, WAVE, EXTRA2, ØNESID
/P1/	P3, R3, U3, V3, P4, R4, U4, V4, P5, R5, U5, V5, PM, RM, UM, VM	B2DATL, UNCØM2, UNEQ, TRED, SLIP, HØBA, VEB4, VEB5, WAKE, EXTRA2, ØNESID

<u>Common Block.</u>	<u>Variables</u>	<u>Subroutines</u>
/UQ/	P3M, R3M, U3M, V3M, P3P, R3P, U3P, V3P, PMP, RMP, UMP, VMP, PMM, RMM, UMM, VMM, DSSUM, YSUM, YSXUM, DSUR, DSUM, DSSLM, YSLM, YSXLM, DSLR, DSLM, RUST, RUS	B2DATL, UNCØM2, UNEQ, TRED, SLIP, HØBA, VEB4, VEB5, WAKE, EXTRA2, ØNESID
/LT/	DELSU, DELSL, DETSU, DETSL	B2DATL, UNCØM2, WAKE, EXTRA2
/YI/	YIDL	B2DATL, UNCØM2, ITER1, EXTRA2
/W/	Y5*, X5*	B2DATL, UNCØM2, UNEQ, SLIP, VEB1, VEB4, VEB5, SURF, WAKE, EXTRA2, ØNESID
/SHEAR/	TAUL, TAUU	UNCØM2, SURF
/XJL/	RJL, PJL, UJL, VJL, EJL	ITER1
/FSMS/	UFS, HFS, UMS, HMS, RMS, RMF, PMS, RFS	ITER1, WAKE, EXTRA2

The current value of 33 must be modified to account for larger values of the maximum allowable value of KS. Its value must be $[3(KS-3)+6]$.

APPENDIX C
PROGRAM LISTING AND AVAILABILITY

Program B2DATL consists of approximately 12,000 lines of FORTRAN instructions and, therefore, a listing is not included as part of this document. However, the program is available from the Computer Software Management and Information Center (COSMIC), Barrow Hall, University of Georgia, Athens, Georgia 30601, to whom all requests for copies should be directed.

1. Report No. NASA CR-2901		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle COMPUTATION OF UNSTEADY TRANSONIC FLOWS THROUGH ROTATING AND STATIONARY CASCADES II - USER'S GUIDE TO FORTRAN PROGRAM B2DATL				5. Report Date December 1977	
				6. Performing Organization Code	
7. Author(s) Edgar Alzner and Paul P. Kalben				8. Performing Organization Report No. ATL TR 205 - Vol. II	
				10. Work Unit No.	
9. Performing Organization Name and Address Advanced Technology Laboratories, Inc. Merrick and Stewart Avenues Westbury, New York 11590				11. Contract or Grant No. NAS3-16807	
				13. Type of Report and Period Covered Contractor Report	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546				14. Sponsoring Agency Code	
15. Supplementary Notes Final report. Project Manager, William D. McNally, Fluid System Components Division, NASA Lewis Research Center, Cleveland, Ohio 44135					
16. Abstract Documentation for the FORTRAN Program B2DATL is provided. The analysis is presented in volume 1 (NASA CR-2900). This volume describes the program input, output, and operational procedures; provides a dictionary of the principal FORTRAN variables; outlines the function of all subroutines; and presents flow charts of the principal subroutines and the main program.					
17. Key Words (Suggested by Author(s)) Unsteady aerodynamics; Internal flows; Rotating machinery analysis; Computational fluid dynamics				18. Distribution Statement Unclassified - unlimited STAR Category 02	
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 78	
				22. Price* A05	

* For sale by the National Technical Information Service, Springfield, Virginia 22161